METHOD OF PREVENTING INFECTIONS FROM BIOTERRORISM AGENTS WITH IMMUNOSTIMULATORY CpG OLIGONUCLEOTIDES

PRIORITY CLAIM

5   This application claims the benefit of U.S. Provisional Application No. 60/422,964, which is incorporated herein by referenced in its entirety.

FIELD

10   The present disclosure relates to a method of inhibiting or treating an infection caused by a bioterrorism agent, specifically to a method of increasing an immune response to a bioterrorism agent using an oligodeoxynucleotide including a CpG motif.

BACKGROUND

15   Bioterrorism agents are bacteria, viruses, and toxins that are dispersed deliberately in an environment to cause disease or death in humans or animals. Bioterrorism agents include, but are not limited to, *Bacillus anthracis* (anthrax), *Yersinia pestis* (plague), *Variola major* (smallpox), tick-borne encephalitis virus

20 (TBEV) (tick-borne encephalitis), and Ebola virus (Ebola). Bioterrorism agents can also include biotoxins, which are toxins produced by certain biological organisms. Exemplary biotoxins are botulinum toxin, which is produced by the bacterium *Clostridium botulinum*, and ricin, which is isolated from castor oil seeds.

     The immune system has evolved two general strategies for combating

25 infections from bioterrorism agents such as anthrax. A rapid "innate" immune response is induced when Toll-like receptors (TLR) on host cells interact with highly conserved pathogen associated molecular patterns (PAMPs) expressed by infectious microorganisms (Marrack and Kappler, *Cell* 76:323, 1994; Medzhitov and Janeway, *Cur. Op. Immunol.* 9:4, 1997). The resultant production of polyreactive

30 antibodies and immunostimulatory cytokines check the pathogen's early proliferation and spread (Marrack and Kappler, *Cell* 76:323, 1994; Medzhitov and Janeway, *Cur. Op. Immunol.* 9:4, 1997; Medzhitov and Janeway, *Cell* 91:295, 1998). A subsequent antigen-specific immune response is then generated against

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determinants unique to the pathogen that helps to eradicate the remaining organisms
and provide long-lasting protective memory.

Vaccination can be used to protect against the effects of some bioterrorism
agents. For example, in the case of anthrax, "protective antigen" (PA) is necessary
5   for vaccine immunogenicity (Ivins et al., *Infect. Immun.* 60:662, 1992; Welkos and
Friedlander, *Microb. Pathog.* 5:127, 1998). Antibodies against PA prevent anthrax
toxin from binding to host cells, thus abrogating toxicity (Little and Ivins, *Microbes.
Infect.* 1:131, 1999). Additionally, antibodies to PA can inhibit the germination of
spores while improving their phagocytosis and killing by macrophages (Welkos et
10   al., *Microbiology* 147:1677, 2001). Unfortunately, the currently licensed human
anthrax vaccine (AVA) requires six vaccinations over eighteen months followed by
yearly boosters to induce and maintain protective anti-PA titers (Pittman et al.,
Vaccine 20:1412, 2002; Pittman et al., *Vaccine* 20:972, 2001). In some vaccinees,
this regimen is associated with undesirable local reactogenicity (Pittman et al.,
15   *Vaccine* 20:972, 2001).

Thus, there exists a need for agents that prevent or treat infections caused by
bioterrorism agents, or that increase the immunogenicity of a vaccine against a
bioterrorism agent, in order to treat or prevent infections in individuals exposed to or
at risk of exposure to bioterrorism agents.

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SUMMARY

Described herein are methods of treating or preventing an infection in a
subject who has been exposed to or is at risk for exposure to a bioterrorism agent. In
25 · some embodiments, the method is a method of increasing an immune response to a
bioterrorism agent using an oligodeoxynucleotide including a CpG motif. Other
methods are methods of increasing an immune response to a bioterrorism agent
using an oligodeoxynucleotide including a CpG motif and an additional anti-
infective agent. Still other methods include enhancing the inmmunogenicity of a
30   vaccine against a bioterrorism agent using an oligodeoxynucleotide including a CpG
motif.

In some embodiments, a therapeutically effective amount of an
immunostimulatory D oligodeoxynucleotide or an immunostimulatory K

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oligodeoxynucleotide is administered to the subject, thereby treating or preventing the infection.

Also described herein are methods of treating or preventing an infection in a subject who has been exposed to or is at risk for exposure to *Bacillus anthracis*. In some embodiments, the method includes administering a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide or an immunostimulatory K oligodeoxynucleotide to a subject.

Other methods described herein are methods of treating or preventing an infection in a subject who has been exposed to or is at risk for exposure to a bioterrorism agent by administering a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide or an immunostimulatory K oligodeoxynucleotide to the subject in combination with an anti-infective agent, thereby treating or preventing the infection.

Further embodiments are methods of treating or preventing an infection in a subject who has been exposed to or is at risk for exposure to *Bacillus anthracis*. In some embodiments, the method includes administering a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide or an immunostimulatory K oligodeoxynucleotide in combination with an anti-infective agent to a subject.

Also described herein are methods of enhancing the immunogenicity of a vaccine against a bioterrorism agent in a subject. In some embodiments, a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide or an immunostimulatory K oligodeoxynucleotide is administered to a subject in combination with a vaccine against a bioterrorism agent, thereby enhancing the immunogenicity of the vaccine against a bioterrorism agent.

Still further embodiments are methods of enhancing the immunogenicity of an antigen from *Bacillus anthracis*, comprising administering to the subject a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide or an immunostimulatory K oligodeoxynucleotide in combination with an antigen from *Bacillus anthracis*, thereby enhancing the immunogenicity of the antigen.

The features and advantages will become more apparent from the following detailed description of several embodiments, which proceeds with reference to the accompanying figures.

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BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 is a graph showing that K ODN significantly increases the maximum, average, and long-term IgG anti-PA response in Rhesus macaques when co-

5   administered with AVA or rPA. Rhesus macaques (5-6/group) were immunized SQ at 0 and 4 weeks with 0.5 ml of AVA or 50 µg of rPA in alum. In some cases, these vaccines were co-administered with 250 µg of an equimolar mixture of K3, K23 and K123 (K) or D19, D29 and D35 (D) ODN. Animals were "challenged" IM with the live attenuated veterinary vaccine strain of anthrax on week 27. Results show the

10   geometric mean (+ SEM) IgG anti-PA titer calculated by analyzing serum from each animal independently at the time points shown. The time-averaged magnitude of the response induced by K ODN plus AVA or rPA significantly exceeded that of either vaccine alone, p <.05.

15   Fig. 2 is a graph showing that K ODN increase serum IgG anti-PA titers and avidity. Six rhesus macaques were immunized SQ at 0 and 4 weeks with 0.5 ml of AVA and then "challenged" IM with the live attenuated veterinary vaccine strain of anthrax on week 27. Serum IgG anti-PA titers and avidity (% of Ab remaining bound after elution with 6 M urea) are shown. Results reflect the geometric mean (+

20   SEM) IgG anti-PA titer derived by analyzing serum from each animal independently at the time points shown.

        Fig 3 is a graph showing that dose and timing of CpG administration influences CpG-mediated protection in mice exposed to Ebola virus. In Fig 3a, mice

25   were treated with 25 - 150 µg of CpG ODN on day 0, and then challenged with 300 LD50 of mouse-adapted Ebola Zaire. In Fig 3b, mice were treated with 100 µg of CpG ODN on the day shown, and then challenged with 300 LD50 of mouse-adapted Ebola Zaire.
        N = 10 mice/group.

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        Fig 4 is a graph showing that CpG ODNs increase survival times in mice exposed to anthrax spores. Mice were treated at the times shown with 100 µg of

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CpG ODN, and then challenged with 11 LD 50 anthrax spores. Survival is shown (N = 10/group).

Fig 5 is a graph that shows the effect of K ODN on the avidity of the anti-PA response. N = 6 per group.

Fig. 6 is a line graph of the geometric mean anti-PA IgG titer following treatment with the anthrax vaccine AVA alone, AVA plus K ODN, AVA plus ODN 10103, and AVA plus ODN 7909.

Fig. 7 is a graph of the geometric mean anti-PA IgM titers following treatment with the anthrax vaccine AVA alone, AVA plus K ODN, AVA plus ODN 10103, and AVA plus ODN 7909.

Fig. 8 is line graph of the geometric mean TNA titers over the entire study period following treatment with the anthrax vaccine AVA alone, AVA plus K ODN, AVA plus ODN 10103, and AVA plus ODN 7909.

Fig. 9 is a graphical representation of the correlation between anti-PA titer and overall survival percentages.

SEQUENCE LISTING

The nucleic acid sequences listed in the accompanying sequence listing are shown using standard letter abbreviations for nucleotide bases, as defined in 37 C.F.R. 1.822. It will be clear to one of skill in the art that whereas the letter X is used in the specification to refer to any unspecified nucleotide, the letter N is used in the Sequence Listing to refer to any unspecified nucleotide. In the accompanying sequence listing:

SEQ ID NOs 1-16, 17, 18, and 21-25 are immunostimulatory CpG D oligonucleotide sequences.

SEQ ID NOs 19, 20, and 26-28 are control D oligonucleotide sequences.

SEQ ID NOs 29-43 are K oligonucleotide sequences.

DETAILED DESCRIPTION

I.   *Abbreviations*

A:	adenine
Ab:	antibody
AVA:	anthrax vaccine adsorbed
C:	cytosine
CpG ODN:	an oligodexoynucleotide (either a D or a K type) including a CpG motif
DC:	dendritic cell
EU:	Endotoxin units
FCS:	fetal calf serum
G:	guanine
h:	hour
IFN-α:	interferon alpha
i.m.:	intramuscular
i.p.:	intraperitoneal
IFN-γ:	interferon gamma
μg:	microgram
mRNA:	messenger ribonucleic acid
NK:	natural killer cells
ODN:	oligodeoxynucleotide
PA:	protective antigen
PAMPs:	pathogen-associated molecular patterns
Pu:	purine
Py:	pyrimidine
rPA:	recombinant PA antigen
SQ:	subcutaneous
T:	thymine
TLR:	Toll-like receptor

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II.   Terms

Unless otherwise noted, technical terms are used according to conventional

usage. Definitions of common terms in molecular biology may be found in

Benjamin Lewin, *Genes V*, published by Oxford University Press, 1994 (ISBN 0-19-

5   854287-9); Kendrew et al. (eds.), *The Encyclopedia of Molecular Biology*, published

by Blackwell Science Ltd., 1994 (ISBN 0-632-02182-9); and Robert A. Meyers

(ed.), *Molecular Biology and Biotechnology: a Comprehensive Desk Reference*,

published by VCH Publishers, Inc., 1995 (ISBN 1-56081-569-8).

In order to facilitate review of the various embodiments of this disclosure,

10   the following explanations of specific terms are provided:

Animal: Living multi-cellular vertebrate organisms, a category that includes,

for example, mammals and birds. The term mammal includes both human and non-

human mammals. Similarly, the term "subject" includes both human and veterinary

15   subjects, for example, humans, non-human primates, dogs, cats, horses, and cows.

Antigen: A compound, composition, or substance that can stimulate the

production of antibodies or a T cell response in an animal, including compositions

that are injected or absorbed into an animal. An antigen reacts with the products of

specific humoral or cellular immunity, including those induced by heterologous

20   immunogens. The term "antigen" includes all related antigenic epitopes. In one

embodiment, an antigen is a bioterrorism agent antigen. In some embodiments, an

antigen is a component of a vaccine against a bioterrorism agent, which is an antigen

associated with or expressed by any bacterium, virus, fungus, or biotoxin that can be

dispersed to cause disease or death in animals or humans.

25   **Anti-infectious agent:** A substance (such as a chemical compound, protein,

antisense oligonucleotide, or other molecule) of use in treating infection of a subject.

Anti-infectious agents include, but are not limited to, anti-fungal compounds, anti-

viral compounds, and antibiotics. Antibiotics include, but are not limited to,

amoxicillin, clarithromycin, cefuroxime, cephalexin ciprofloxacin, doxycycline,

30   metronidazole, terbinafine, levofloxacin, nitrofurantoin, tetracycline, and

azithromycin. Anti-fungal compounds, include, but are not limited to, clotrimazole,

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butenafine, butoconazole, ciclopirox, clioquinol, clioquinol, clotrimazole, econazole, fluconazole, flucytosine, griseofulvin, haloprogin, itraconazole, ketoconazole, miconazole, naftifine, nystatin, oxiconazole, sulconazole, terbinafine, terconazole, tioconazole, and tolnaftate. Anti-viral compounds, include, but are not limited to,

5   zidovudine, didanosine, zalcitabine, stavudine, lamivudine, abacavir, tenofovir, nevirapine, delavirdine, efavirenz, saquinavir, ritonavir, indinavir, nelfinavir, saquinavir, amprenavir, and lopinavir. Anti-infectious agents also include hyper-immune globulin. Hyper-immune globulin is gamma globulin isolated from a donor, or from a pool of donors, that has been immunized with a substance of

10   interest. Specifically, hyper-immune globulin is antibody purified from a donor who was repeatedly vaccinated against a pathogen. In several embodiments, hyper-immune globulin is gamma globulin isolated from a donor, or from a pool of donors, repeatedly immunized with an antigen, a micro-organism (including a heat-killed micro-organism), or a virus. In one specific, non-limiting example, hyper-immune

15   globulin against anthrax is produced using serum from a donor repeatedly immunized with the anthrax vaccine (AVA).

            Antisense, Sense and Antigene: Double-stranded DNA (dsDNA) has two strands, a 5' -> 3' strand, referred to as the plus strand, and a 3' -> 5' strand (the reverse compliment), referred to as the minus strand. Because RNA polymerase

20   adds nucleic acids in a 5' -> 3' direction, the minus strand of the DNA serves as the template for the RNA during transcription. Thus, the RNA formed will have a sequence complementary to the minus strand and identical to the plus strand (except that U is substituted for T).

            Antisense molecules are molecules that are specifically hybridizable or

25   specifically complementary to either RNA or the plus strand of DNA. Sense molecules are molecules that are specifically hybridizable or specifically complementary to the minus strand of DNA. Antigene molecules are either antisense or sense molecules directed to a dsDNA target. In one embodiment, an antisense molecule specifically hybridizes to a target mRNA and inhibits

30   transcription of the target mRNA.

            AVA: The only licensed human anthrax vaccine in the United States, AVA, is produced by BioPort Corporation in Lansing, MI, and is prepared from a cell-free

filtrate of *B. anthracis* culture that contains no dead or live bacteria. The strain used to prepare the vaccine is a toxigenic, nonencapsulated strain known as V770-NP1-R. The filtrate contains a mix of cellular products including PA (protective antigen) and is adsorbed to aluminum hydroxide (Amphogel, Wyeth Laboratories) as adjuvant.

5   The amount of PA and other proteins per 0.5mL dose is unknown, and all three toxin components, LF (lethal factor), EF (edema factor), and PA, are present in the product.

Generally, primary vaccination generally consists of three subcutaneous injections at 0, 2, and 4 weeks, and three booster vaccinations at 6, 12, and 18

10   months. To maintain immunity, the manufacturer recommends an annual booster injection. However, schedules with a reduced number of doses and with intramuscular (IM) administration have been proposed. Following a suspected exposure to *B. anthracis*, AVA may be given concurrently with antibiotic prophylaxis.

15   ***Bacillus Anthracis***: The etiologic agent of anthrax, *Bacillus anthracis* is a large, gram-positive, nonmotile, spore-forming bacterial rod. The three virulence factors of *B. anthracis* are edema toxin, lethal toxin and a capsular antigen. Infection with *B. anthracis* is the cause of human anthrax disease. Human anthrax has three major clinical forms: cutaneous, inhalation, and gastrointestinal.

20   Cutaneous anthrax is a result of introduction of the spore through the skin; inhalation anthrax, through the respiratory tract; and gastrointestinal anthrax, by ingestion. If untreated, anthrax in all forms can lead to septicemia and death. Early treatment of cutaneous anthrax is usually curative, and early treatment of all forms is important for recovery. Patients with gastrointestinal anthrax have reported case-

25   fatality rates ranging from 25% to 75%. Case-fatality rates for inhalational anthrax are thought to approach 90 to 100%.

Bacillus anthracis secretes a toxin made up of three proteins: protective antigen (PA), oedema factor (OF) and lethal factor (LF) (Stanley et al., *J. Gen. Microbiol.* 26:49-66, 1961; Beall et al., *J. Bacteriol.* 83:1274-1280, 1962). PA binds

30   to cell-surface receptors on the host's cell membranes. After being cleaved by a protease (Bradley et al., *Nature* 414:225, 2001), PA binds to the two toxic enzymes, OF and LA, and mediates their transportation into the cytosol where they exert their

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pathogenic effects. Thus, the smaller cleaved 63 kD PA remnant (PA_{63}) oligomerizes features a newly exposed, second binding domain and binds to either EF, an 89 kD protein, to form edema toxin, or LF, a 90 kD protein, to form lethal toxin (LeTx) (Leppla et al., *Salisbury Med. Bull. Suppl.* 68:41-43, 1990), and the

5   complex is internalized into the cell (Singh et al., *Infect. Immun.* 67:1853, 1999; Friedlander, *J. Biol. Chem.* 261:7123, 1986). From these endosomes, the PA_{63} channel enables translocation of LF and EF to the cytosol by a pH- and voltage-dependent mechanism (Zhao et al., *J. Biol. Chem,* 270:18626, 1995).

Bioterrorism agents: Any of various bacteria, viruses, and toxins that can

10   be dispersed deliberately to cause disease or death to humans or animals. Examples of bioterrorism agents include *Bacillus anthracis,* which causes anthrax, *Yersinia pestis,* which causes plague, and *Variola major,* which causes smallpox, tick-borne encephalitis virus (TBEV), which causes tick-borne encephalitis, and Ebola virus, which causes Ebola. Bioterrorism agents also include biotoxins, which are toxins

15   produced by certain biological organisms. Exemplary biotoxins are botulinum toxin, produced by the bacterium *Clostridium botulinum,* and ricin isolated from castor oil seeds. Western counter-proliferation agencies currently recognize 23 types of bacteria, 43 types of viruses, and 14 types of biotoxins as potential bioterrorism agents.

20   Other examples of bioterrorism agents include, but are not limited to, *Escherichia coli, Haemophilus influenzae,* cobra venom, shellfish toxin, botulinum toxin, saxitoxin, ricin toxin, *Shigella flexneri, S. dysenteriae (Shigella bacillus), Salmonella, Staphylococcus* enterotoxin B, *Histoplasma capsulatum,* tricothecene mycotoxin, aflatoxin. Bioterrorism agents can also result in cryptococcosis,

25   brucellosis (undulant fever), coccidioidomycosis (San Joaquin Valley or desert fever), psittacosis (parrot fever), bubonic plague, tularemia (rabbit fever), malaria, cholera, typhoid, hemorrhagic fever, tick-borne encephalitis, Venezuelan equine encephalitis, pneumonic plague, Rocky Mountain spotted fever, dengue fever, Rift Valley fever, diphtheria, melioidosis, glanders, tuberculosis, infectious hepatitis,

30   encephalitides, blastomycosis, nocardiosis, yellow fever, typhus, and Q fever.

CpG or CpG motif: A nucleic acid having a cytosine followed by a guanine linked by a phosphate bond in which the pyrimidine ring of the cytosine is

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unmethylated. The term "methylated CpG" refers to the methylation of the cytosine on the pyrimidine ring, usually occurring at the 5-position of the pyrimidine ring. A CpG motif is a pattern of bases that include an unmethylated central CpG surrounded by at least one base flanking (on the 3' and the 5' side of) the central

5   CpG. Without being bound by theory, the bases flanking the CpG confer part of the activity to the CpG oligodeoxynucleotide. A CpG oligonucleotide is an oligonucleotide that is at least about ten nucleotides in length and includes an unmethylated CpG. CpG oligonucleotides include both D and K oligodeoxynucleotides (see below). CpG oligodeoxynucleotides are single-stranded.

10   The entire CpG oligodeoxynucleotide can be unmethylated or portions may be unmethylated. In one embodiment, at least the C of the 5' CG 3' is unmethylated.
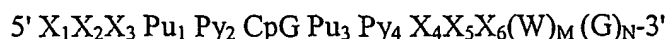
       Cytokine: Proteins made by cells that affect the behavior of other cells, such as lymphocytes. In one embodiment, a cytokine is a chemokine, a molecule that affects cellular trafficking. Specific non-limiting examples of cytokines are

15   IFN-γ, IL-6, and IL-10.

       D Type Oligodeoxynucleotide (D ODN): An oligodeoxynucleotide including an unmethylated CpG motif that has a sequence represented by the formula:

$$5' \text{ RY-CpG-RY } 3'$$

20   wherein the central CpG motif is unmethylated, R is A or G (a purine), and Y is C or T (a pyrimidine). D-type oligodeoxynucleotides include an unmethylated CpG dinucleotide. Inversion, replacement or methylation of the CpG reduces or abrogates the activity of the D oligodeoxynucleotide.

       In one embodiment, a D type ODN is at least about 16 nucleotides in length

25   and includes a sequence represented by Formula III:

$$5' \text{ } X_1X_2X_3 \text{ } Pu_1 \text{ } Py_2 \text{ CpG } Pu_3 \text{ } Py_4 \text{ } X_4X_5X_6(W)_M \text{ } (G)_N\text{-}3'$$

wherein the central CpG motif is unmethylated, Pu is a purine nucleotide, Py is a pyrimidine nucleotide, X and W are any nucleotide, M is any integer from 0 to 10, and N is any integer from 4 to 10. Generally D ODNs can stimulate a cellular

30   response. For example, D ODNs stimulate natural killer cells and the maturation of dendritic cells.

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Epitope: An antigenic determinant. These are particular chemical groups or peptide sequences on a molecule that are antigenic, i.e., that elicit a specific immune response. An antibody binds a particular antigenic epitope.

Functionally Equivalent: Sequence alterations, for example in an
5 immunostimulatory ODN, that yield the same results as described herein. Such sequence alterations can include, but are not limited to, deletions, base modifications, mutations, labeling, and insertions.

Immune response: A response of a cell of the immune system, such as a B cell or a T cell, to a stimulus. In one embodiment, the response is specific for a
10 particular antigen (an "antigen-specific response"). A "parameter of an immune response" is any particular measurable aspect of an immune response, including, but not limited to, cytokine secretion (IL-6, IL-10, IFN-γ, etc.), immunoglobulin production, dendritic cell maturation, and proliferation of a cell of the immune system. One of skill in the art can readily determine an increase in any one of these
15 parameters, using known laboratory assays. In one specific non-limiting example, to assess cell proliferation, incorporation of ^{3}H-thymidine can be assessed. A "substantial" increase in a parameter of the immune response is a significant increase in this parameter as compared to a control. Specific, non-limiting examples of a substantial increase are at least about a 50% increase, at least about a 75%
20 increase, at least about a 90% increase, at least about a 100% increase, at least about a 200% increase, at least about a 300% increase, and at least about a 500% increase. One of skill in the art can readily identify a significant increase using known statistical methods. One specific, non-limiting example of a statistical test used to assess a substantial increase is the use of a Z test to compare the percent of samples
25 that respond to a vaccine against a bioterrorism agent alone as compared to the percent of samples that respond using a vaccine against a bioterrorism agent administered in conjunction with an immunostimulatory ODN. A non-parametric ANOVA can be used to compare differences in the magnitude of the response induced by vaccine alone as compared to the percent of samples that respond using
30 vaccine administered in conjunction with an immunostimulatory ODN. In this example, p $\leq$ 0.05 is significant, and indicates a substantial increase in the parameter

of the immune response. One of skill in the art can readily identify other statistical assays of use.

An "immunoprotective response" is an immune response that results in a decrease of symptoms upon infection with a bioterrorism agent or results in a delay or prevention of a disease associated with infection. "Enhancing the immunogenicity of a vaccine" is an example of an increase in an immune response.

Inhibiting or treating a disease: "Inhibiting" a disease refers to reducing the full development of a disease, for example in a person who is known to have a predisposition to a disease such as a person who has been or is at risk for being exposed to a bioterrorism agent. Examples of persons at risk for being exposed to a bioterrorism agent include, but are not limited to, military personnel, mail handlers, medical personnel, and governmental officials, as well as those with weakened immune systems, for example, the elderly, people on immunosuppressive drugs, subjects with cancer, and subjects infected with HIV. "Treatment" refers to a therapeutic intervention that ameliorates a sign or symptom of a disease or pathological condition after it has begun to develop.

Isolated: An "isolated" biological component (such as a nucleic acid, peptide or protein) has been substantially separated, produced apart from, or purified away from other biological components in the cell of the organism in which the component naturally occurs, i.e., other chromosomal and extrachromosomal DNA and RNA, and proteins. Nucleic acids, peptides and proteins which have been "isolated" thus include nucleic acids and proteins purified by standard purification methods. The term also embraces nucleic acids, peptides and proteins prepared by recombinant expression in a host cell as well as chemically synthesized nucleic acids.

K Type Oligodeoxynucleotide (K ODN): An oligodeoxynucleotide including an unmethylated CpG motif that has a sequence represented by the formula:

$$5' \ N_1N_2N_3Q\text{-}CpG\text{-}WN_4N_5N_6 \ 3'$$

wherein the central CpG motif is unmethylated, Q is T, G or A, W is A or T, and N_1, N_2, N_3, N_4, N_5, and N_6 are any nucleotides. In one embodiment, Q is a T. K type CpG ODNs have been previously described (see U.S. Patent No. 6,194,388; U.S.

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Patent No. 6,207,646; U.S. Patent No. 6,214,806; U.S. Patent No. 6,218,371; U.S.

Patent No. 6,239,116, U.S. Patent No. 6,339,068; U.S. Patent No. 6,406,705 and

U.S. Patent No. 6,429,199, which are herein incorporated by reference). Generally

K ODNs can stimulate a humoral response. For example, K ODNs stimulate the

5   production of IgM.

   Leukocyte: Cells in the blood, also termed "white cells," that are involved

in defending the body against infective organisms and foreign substances.

Leukocytes are produced in the bone marrow. There are 5 main types of white

blood cell, subdivided between 2 main groups: polymorphomnuclear leukocytes

10   (neutrophils, eosinophils, basophils) and mononuclear leukocytes (monocytes and

lymphocytes). When an infection is present, the production of leukocytes increases.

   Mammal: This term includes both human and non-human mammals.

Similarly, the term "subject" includes both human and veterinary subjects.

   Nucleic acid: A deoxyribonucleotide or ribonucleotide polymer in either

15   single or double stranded form, and unless otherwise limited, encompasses known

analogues of natural nucleotides that hybridize to nucleic acids in a manner similar

to naturally occurring nucleotides.

   Oligonucleotide or **"oligo":** Multiple nucleotides (i.e. molecules

comprising a sugar (e.g. ribose or deoxyribose) linked to a phosphate group and to

20   an exchangeable organic base, which is either a substituted pyrimidine (Py) (e.g.

cytosine (C), thymine (T) or uracil (U)) or a substituted purine (Pu) (e.g. adenine (A)

or guanine (G)). The term "oligonucleotide" as used herein refers to both

oligoribonucleotides (ORNs) and oligodeoxyribonucleotides (ODNs). The term

"oligonucleotide" also includes oligonucleosides (i.e. an oligonucleotide minus the

25   phosphate) and any other organic base polymer. Oligonucleotides can be obtained

from existing nucleic acid sources (e.g. genomic or cDNA), but are preferably

synthetic (e.g. produced by oligonucleotide synthesis).

   A "stabilized oligonucleotide" is an oligonucleotide that is relatively resistant

to *in vivo* degradation (for example via an exo- or endo-nuclease). In one

30   embodiment, a stabilized oligonucleotide has a modified phosphate backbone. One

specific, non-limiting example of a stabilized oligonucleotide has a

phosphorothioate modified phosphate backbone (wherein at least one of the

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phosphate oxygens is replaced by sulfur). Other stabilized oligonucleotides include: nonionic DNA analogs, such as alkyl- and aryl- phosphonates (in which the charged phosphonate oxygen is replaced by an alkyl or aryl group), phosphodiester and alkylphosphotriesters, in which the charged oxygen moiety is alkylated.

5   Oligonucleotides which contain a diol, such as tetraethyleneglycol or hexaethyleneglycol, at either or both termini have also been shown to be substantially resistant to nuclease degradation.

An "immunostimulatory oligonucleotide," "immunostimulatory CpG containing oligodeoxynucleotide," "CpG ODN," refers to an oligodeoxynucleotide,

10   which contains a cytosine, guanine dinucleotide sequence and stimulates (e.g. has a mitogenic effect) vertebrate immune cells. The cytosine, guanine is unmethylated. The term "immunostimulatory ODN" includes both D and K type ODNs.

An "oligonucleotide delivery complex" is an oligonucleotide associated with (e.g. ionically or covalently bound to; or encapsulated within) a targeting means

15   (e.g. a molecule that results in a higher affinity binding to a target cell (e.g. B cell or natural killer (NK) cell) surface and/or increased cellular uptake by target cells). Examples of oligonucleotide delivery complexes include oligonucleotides associated with: a sterol (e.g. cholesterol), a lipid (e.g. cationic lipid, virosome or liposome), or a target cell specific binding agent (e.g. a ligand recognized by a target cell specific

20   receptor). Preferred complexes must be sufficiently stable *in vivo* to prevent significant uncoupling prior to internalization by the target cell. However, the complex should be cleavable or otherwise accessible under appropriate conditions within the cell so that the oligonucleotide is functional. (Gursel, *J. Immunol.* 167: 3324, 2001)

25   **Protective Antigen (PA):** *Bacillus anthracis* secretes a toxin made up of three proteins: protective antigen (PA), edema factor (EF) and lethal factor (LF). PA binds to cell-surface receptors on the host's cell membranes. After being cleaved by a protease, PA binds to the two toxic enzymes, EF and LA, and mediates their transportation into the cytosol where they exert their pathogenic effects.

30   The only licensed human anthrax vaccine in the United States, AVA, contains a mix of cellular products including PA (protective antigen). The sequence

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of the protection antigen is known, as is set forth as GenBank Accession No. 13423, which is incorporated herein by reference. Vaccine preparations including PA are described, for example, in U.S. Patent No. 5,591,631, which is incorporated herein by reference. Recombinant Protective Antigen (rPA) is an anthrax vaccine that is

5 currently under development. rPA is a recombinant version of the PA vaccine.

Pharmaceutical agent or drug: A chemical compound or composition capable of inducing a desired therapeutic or prophylactic effect when properly administered to a subject. Pharmaceutical agents include, but are not limited to, anti-infective agents, such as antibiotics, anti-fungal compounds, anti-viral

10 compounds, and hyper-immune globulin.

Pharmaceutically acceptable carriers: The pharmaceutically acceptable carriers useful in this disclosure are conventional. *Remington's Pharmaceutical Sciences*, by E. W. Martin, Mack Publishing Co., Easton, PA, 15th Edition (1975), describes compositions and formulations suitable for pharmaceutical delivery of the

15 fusion proteins herein disclosed.

In general, the nature of the carrier will depend on the particular mode of administration being employed. For instance, parenteral formulations usually comprise injectable fluids that include pharmaceutically and physiologically acceptable fluids such as water, physiological saline, balanced salt solutions,

20 aqueous dextrose, glycerol or the like as a vehicle. For solid compositions (e.g., powder, pill, tablet, or capsule forms), conventional non-toxic solid carriers can include, for example, pharmaceutical grades of mannitol, lactose, starch, or magnesium stearate. In addition to biologically-neutral carriers, pharmaceutical compositions to be administered can contain minor amounts of non-toxic auxiliary

25 substances, such as wetting or emulsifying agents, preservatives, and pH buffering agents and the like, for example sodium acetate or sorbitan monolaurate.

Self-complementary nucleic acid sequence: A nucleic acid sequence that can form Watson-Crick base pairs. The four bases characteristic of deoxyribonucleic unit of DNA are the purines (adenine and guanine) and the

30 pyrimidines (cytosine and thymine). Adenine pairs with thymine via two hydrogen bonds, while guanine pairs with cytosine via three hydrogen bonds. If a nucleic acid sequence includes two or more bases in sequence that can form hydrogen bonds with

17

two or more other bases in the same nucleic acid sequence, then the nucleic acid includes a self-complementary sequence.

Therapeutically effective dose: A dose sufficient to prevent advancement, or to cause regression of the disease, or which is capable of relieving symptoms

5   caused by the disease, such as fever, respiratory symptoms, pain or swelling.

Vaccine: A preparation of antigen, DNA, protein subunit, peptide, attenuated microorganisms (including but not limited to bacteria and viruses), living microorganisms, or killed microorganisms, administered for the inhibition, prevention, amelioration or treatment of infectious disease. In some embodiments,

10   the vaccine against a bioterrorism agent includes an antigen from a bioterrorism agent, for example AVA or PA.

Generally, the first step in making a vaccine is to isolate or create an organism, or part of one, that is unable to cause the disease, but that still retains the antigens responsible for inducing the host's immune response. This can be done in

15   many ways. One way is to kill the organism using heat or formalin; vaccines produced in this way are called "inactivated" or "killed" vaccines. Examples of killed vaccines in common use today are the typhoid vaccine and the Salk poliomyelitis vaccine.

Another way to produce a vaccine is to use only the antigenic part of the

20   disease-causing organism, for example the capsule, the flagella, or part of the protein cell wall; these types of vaccines are called "acellular vaccines." An example of an acellular vaccine is the *Haemophilus influenzae* B (HIB) vaccine. Acellular vaccines exhibit some similarities to killed vaccines: neither killed nor acellular vaccines generally induce the strongest immune responses and may therefore require

25   a "booster" every few years to insure their continued effectiveness. In addition, neither killed nor acellular vaccines can cause disease and are therefore considered to be safe for use in immunocompromised patients.

A third way of making a vaccine is to "attenuate" or weaken a live microorganism by mutating the organism to alter its growth capabilities. In one

30   embodiment, an attenuated vaccine is not replication competent or lacks essential proteins. Examples of attenuated vaccines are those that protect against measles,

18

mumps, and rubella. Immunity is often life-long with attenuated vaccines and does
not require booster shots.

Vaccines can also be produced from a toxin. In these cases, the toxin is often
treated with aluminum or adsorbed onto aluminum salts to form a "toxoid."

5   Examples of toxoids are the diphtheria and the tetanus vaccines. Vaccines made
from toxoids often induce low-level immune responses and are therefore sometimes
administered with an "adjuvant" - an agent which increases the immune response.
For example, the diphtheria and tetanus vaccines are often combined with the
pertussis vaccine and administered together as a DPT immunization. The pertussis

10 acts as an adjuvant in this vaccine. When more than one vaccine is administered
together it is called a "conjugated vaccine."

Another way of making a vaccine is to use an organism which is similar to
the virulent organism but that does not cause serious disease, such as using the
cowpox virus to protect against infection with smallpox virus, or BCG vaccine, an

15 attenuated strain of *Mycobacterium bovis*, used to protect against *Mycobacterium
tuberculosis*.

"Subunit vaccines" are vaccines which use a polypeptide from an infectious
organism to stimulate a strong immune response. An "antigen vaccine" uses an
immunogenic epitope of a polypeptide to induce a protective immune response. A

20 "DNA vaccine" uses a nucleic acid encoding an antigen to induce a protective
immune response.

A "vaccine against a bioterrorism agent" can be, but is not limited to, a heat
or formalin-killed vaccine, attenuated vaccine, subunit vaccine, antigen vaccine,
DNA vaccine, acellular vaccine, or toxoid vaccine directed against *Bacillus*

25 *anthracis*, *Yersinia pestis*, *Variola major*, tick-borne encephalitis virus (TBEV),
Ebola virus, *Escherichia coli*, *Haemophilus influenzae*, cobra venom, shellfish toxin,
botulinum toxin, saxitoxin, ricin toxin, *Shigella flexneri*, *S. dysenteriae* (*Shigella
bacillus*), *Salmonella*, *Staphylococcus* enterotoxin B, *Histoplasma capsulatum*,
tricothecene mycotoxin, aflatoxin. A "vaccine against a bioterrorism agent" can also

30 be used to induce a protective immune response against cryptococcosis, brucellosis
(undulant fever), coccidioidomycosis (San Joaquin Valley or desert fever),
psittacosis (parrot fever), bubonic plague, tularemia (rabbit fever), malaria, cholera,

typhoid, hemorrhagic fever, tick-borne encephalitis, Venezuelan equine encephalitis, pneumonic plague, Rocky Mountain spotted fever, dengue fever, Rift Valley fever, diphtheria, melioidosis, glanders, tuberculosis, infectious hepatitis, encephalitides, blastomycosis, nocardiosis, yellow fever, typhus, and Q fever.

5   **Virus:** A microscopic infectious organism that reproduces inside living cells. A virus consists essentially of a core of a single nucleic acid surrounded by a protein coat, and has the ability to replicate only inside a living cell. "Viral replication" is the production of additional virus by the occurrence of at least one viral life cycle. A virus may subvert the host cells' normal functions, causing the

10   cell to behave in a manner determined by the virus. For example, a viral infection may result in a cell producing a cytokine, or responding to a cytokine, when the uninfected cell does not normally do so.

       Unless otherwise explained, all technical and scientific terms used herein

15   have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. The singular terms "a," "an," and "the" include plural referents unless context clearly indicates otherwise. Similarly, the word "or" is intended to include "and" unless the context clearly indicates otherwise. It is further to be understood that all base sizes or amino acid sizes, and all molecular

20   weight or molecular mass values, given for nucleic acids or polypeptides are approximate, and are provided for description. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of this disclosure, suitable methods and materials are described below. The term "comprises" means "includes." All publications, patent applications, patents, and

25   other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including explanations of terms, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

20

III.   Description of Several Embodiments

A.   D and K-type ODNs

The present disclosure relates to a class of DNA motifs that stimulates

5   immune activation, for example the innate immune response or the adaptive immune

response by B cells, monocytes, dendritic cells, and natural killer (NK) cells. K type

CpG ODNs have been previously described (see U.S. Patent No. 6,194,388; U.S.

Patent No. 6,207,646; U.S. Patent No. 6,214,806; U.S. Patent No. 6,218,371; U.S.

Patent No. 6,239,116, U.S. Patent No. 6,339,068; U.S. Patent No. 6,406,705 and

10   U.S. Patent No. 6,429,199, which are herein incorporated by reference). K ODNs

that exhibit the greatest immunostimulatory activity share specific characteristics.

These characteristics differ from those of the Formula II or D ODN (see below). In

addition, K ODNs have specific effects on the cells of the immune system, which

differ from the effects of D ODN. For example, K ODNs stimulate proliferation of

15   B cells and stimulate the production of IL-6.

The K ODNs include at least about 10 nucleotides and include a sequence

represented by Formula I:

$$5' \ N_1N_2N_3T\text{-}CpG\text{-}WN_4N_5N_6 \ 3'$$

20

wherein the central CpG motif is unmethylated, W is A or T, and N_1, N_2, N_3, N_4, N_5,

and N_6 are any nucleotides.

These Formula I or K ODNs stimulate B cell proliferation and the secretion

of IgM and IL-6, processes involved in the body's humoral immunity, such as the

25   production of antibodies against foreign antigens. In one embodiment, the K ODNs

induce a humoral immune response.

Certain K oligonucleotides are of the formula:

$$5' \ N_1N_2N_3T\text{-}CpG\text{-}WN_4N_5N_6 \ 3'$$

30

contain a phosphate backbone modification. In one specific, non-limiting example,

the phosphate backbone modification is a phosphorothioate backbone modification

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(i.e., one of the non-bridging oxygens is replaced with sulfur, as set forth in International Patent Application WO 95/26204, herein incorporated by reference). In one embodiment, K ODNs have a phosphorothioate backbone, and at least one unmethylated CpG dinucleotide. Eliminating the CpG dinucleotide motif from the

5   K ODN significantly reduces immune activation. Incorporating multiple CpGs in a single K ODN increases immune stimulation. In some embodiments, the K ODNs are at least 12 bases long. In addition, K ODNs containing CpG motifs at the 5' end are the most stimulatory, although at least one base upstream of the CpG is required. More particularly, the most active K ODNs contain a thymidine immediately 5'

10 from the CpG dinucleotide, and a TpT or a TpA in a position 3' from the CpG motif. Modifications which are greater than 2 base pairs from the CpG dinucleotide motif appear to have little effect on K ODN activity.

Examples of a K ODN include, but are not limited to:

15   TCCATGTCGCTCCTGATGCT   (SEQ ID NO: 29)
          TCCATGTCGTTCCTGATGCT   (SEQ ID NO: 30)
          TCGTCGTTTTGTCGTTTTGTCGT   (SEQ ID NO: 31)
          TCGTCGTTGTCGTTGTCGTT   (SEQ ID NO: 32)
          TCGTCGTTTTGTCGTTTGTCGTT   (SEQ ID NO: 33)

20   TCGTCGTTGTCGTTTTGTCGTT (SEQ ID NO: 34)
          GCGTGCGTTGTCGTTGTCGTT   (SEQ ID NO: 35)
          TGTCGTTTGTCGTTTGTCGTT   (SEQ ID NO: 36)
          TGTCGTTGTCGTTGTCGTT   (SEQ ID NO: 37)
          TCGTCGTCGTCGTT   (SEQ ID NO: 38).

25   TCCTGTCGTTCCTTGTCGTT   (SEQ ID NO: 39)
          TCCTGTCGTTTTTTGTCGTT (SEQ ID NO: 40)
          TCGTCGCTGTCTGCCCTTCTT (SEQ ID NO: 41)
          TCGTCGCTGTTGTCGTTTCTT (SEQ ID NO: 42)
          TCCATGACGTTCCTGACGTT   (SEQ ID NO: 43)

30

In particular, non-limiting examples, the K oligodeoxynucleotide includes a sequence selected from the group consisting of SEQ ID NO: 29, SEQ ID NO: 30,

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SEQ ID NO: 31, SEQ ID NO: 32, SEQ ID NO: 33, SEQ ID NO: 34, SEQ ID NO: 35, SEQ ID NO: 36, SEQ ID NO: 37, SEQ ID NO: 38, SEQ ID NO: 39, SEQ ID NO: 40, SEQ ID NO: 41, SEQ ID NO: 42, and SEQ ID NO: 43.

5
D ODNs differ both in structure and activity from K ODNs. The unique activities of D ODNs are disclosed below. For example, as disclosed herein, D oligodeoxynucleotides stimulate the release of cytokines from cells of the immune system. In specific, non-limiting examples, D oligonucleotides stimulate the release or production of IP-10 and IFN-α by monocytes and/or plasmacytoid dendritic cells and the release or production of IFN-γ by NK cells. The stimulation of NK cells by

10
D oligodeoxynucleotides can be either direct or indirect.

With regard to structure, a CpG motif in D oligonucleotides can be described by Formula II:

$$5'\ RY\text{-}CpG\text{-}RY\ 3'$$

15

wherein the central CpG motif is unmethylated, R is A or G (a purine), and Y is C or T (a pyrimidine). D oligonucleotides include an unmethylated CpG dinucleotide. Inversion, replacement or methylation of the CpG reduces or abrogates the activity of the D oligonucleotide.

20
Certain D ODNs are at least about 16 nucleotides in length and includes a sequence represented by Formula III:
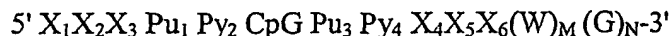
$$5'\ X_1 X_2 X_3\ Pu_1\ Py_2\ CpG\ Pu_3\ Py_4\ X_4 X_5 X_6 (W)_M\ (G)_N\text{-}3'$$

25
wherein the central CpG motif is unmethylated, Pu is a purine nucleotide, Py is a pyrimidine nucleotide, X and W are any nucleotide, M is any integer from 0 to 10, and N is any integer from 4 to 10.

The region $Pu_1\ Py_2\ CpG\ Pu_3\ Py_4$ is termed the CpG motif. The region $X_1 X_2 X_3$ is termed the 5' flanking region, and the region $X_4 X_5 X_6$ is termed the 3'

30
flanking region. If nucleotides are included 5' of $X_1 X_2 X_3$ in the D ODN, these nucleotides are termed the 5' far flanking region. Nucleotides 3' of $X_4 X_5 X_6$ in the D ODN are termed the 3' far flanking region.

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In one specific, non-limiting example, Py_2 is a cytosine. In another specific, non-limiting example, Pu_3 is a guanidine. In yet another specific, non-limiting example, Py_2 is a thymidine and Pu_3 is an adenine. In a further specific, non-limiting example, Pu_1 is an adenine and Py_2 is a tyrosine. In another specific, non-limiting example, Pu_3 is an adenine and Py_4 is a tyrosine.

In one specific, not limiting example, N is from about 4 to about 8. In another specific, non-limiting example, N is about 6.

D CpG oligonucleotides can include modified nucleotides. Without being bound by theory, modified nucleotides can be included to increase the stability of a D oligonucleotide. Without being bound by theory, because phosphorothioate-modified nucleotides confer resistance to exonuclease digestion, the D ODN are "stabilized" by incorporating phosphorothioate-modified nucleotides. In one embodiment, the CpG dinucleotide motif and its immediate flanking regions include phosphodiester rather than phosphorothioate nucleotides. In one specific non-limiting example, the sequence Pu_1 Py_2 CpG Pu_3 Py_4 includes phosphodiester bases. In another specific, non-limiting example, all of the bases in the sequence Pu_1 Py_2 CpG Pu_3 Py_4 are phosphodiester bases. In yet another specific, non-limiting example, $X_1X_2X_3$ and $X_4X_5X_6(W)_M$ $(G)_N$ include phosphodiester bases. In yet another specific, non-limiting example, $X_1X_2X_3$ Pu_1 Py_2 CpG Pu_3 Py_4 $X_4X_5X_6(W)_M$ $(G)_N$ include phosphodiester bases. In further non-limiting examples, the sequence $X_1X_2X_3$ includes at most one or at most two phosphothioate bases and/or the sequence $X_4X_5X_6$ includes at most one or at most two phosphotioate bases. In additional non-limiting examples, $X_4X_5X_6(W)_M$ $(G)_N$ includes at least 1, at least 2, at least 3, at least 4, or at least 5 phosphothioate bases. Thus, a D oligodeoxynucleotide can be a phosphorothioate/phosphodiester chimera.

As disclosed herein, any suitable modification can be used in the present disclosure to render the D oligodeoxynucleotide resistant to degradation *in vivo* (e.g., via an exo- or endo-nuclease). In one specific, non-limiting example, a modification that renders the oligodeoxynucleotide less susceptible to degradation is the inclusion of nontraditional bases such as inosine and quesine, as well as acetyl-, thio- and similarly modified forms of adenine, cytidine, guanine, thymine, and

uridine. Other modified nucleotides include nonionic DNA analogs, such as alkyl or aryl phosphonates (i.e., the charged phosphonate oxygen is replaced with an alkyl or aryl group, as set forth in U.S. Patent No. 4,469,863), phosphodiesters and alkylphosphotriesters (i.e., the charged oxygen moiety is alkylated, as set forth in

5   U.S. Patent No. 5,023,243 and European Patent No. 0 092 574). Oligonucleotides containing a diol, such as tetraethyleneglycol or hexaethyleneglycol, at either or both termini, have also been shown to be more resistant to degradation. The D oligodeoxynucleotides can also be modified to contain a secondary structure (e.g., stem loop structure). Without being bound by theory, it is believed that

10   incorporation of a stem loop structure renders and oligodeoxynucleotide more effective.

In a further embodiment, $Pu_1 Py_2$ and $Pu_3 Py_4$ are self-complementary. In another embodiment, $X_1X_2X_3$ and $X_4X_5X_6$ are self complementary. In yet another embodiment $X_1X_2X_3 Pu_1 Py_2$ and $Pu_3 Py_4 X_4X_5X_6$ are self complementary.

15   Specific non-limiting examples of a D oligonucleotide wherein $Pu_1 Py_2$ and $Pu_3 Py_4$ are self-complementary include, but are not limited to, ATCGAT (SEQ ID NO: 9), ACCGGT (SEQ ID NO: 10), ATCGAC (SEQ ID NO: 11), ACCGAT (SEQ ID NO: 12), GTCGAC (SEQ ID NO: 13), or GCCGGC (SEQ ID NO: 14). Without being bound by theory, the self-complementary base sequences can help to form a

20   stem-loop structure with the CpG dinucleotide at the apex to facilitate immunostimulatory functions. Thus, in one specific, non-limiting example, D oligonucleotides wherein $Pu_1 Py_2$ and $Pu_3 Py_4$ are self-complementary induce higher levels of IFN-γ production from a cell of the immune system (see below). The self-complementary need not be limited to $Pu_1 Py_2$ and $Pu_3 Py_4$. Thus, in another

25   embodiment, additional bases on each side of the three bases on each side of the CpG-containing hexamer form a self-complementary sequence (see above).

One specific non-limiting example of a sequence wherein $Pu_1 Py_2$ and $Pu_3 Py_4$ are self-complementary but wherein the far-flanking sequences are not self-complementary is:

30   GGTGCATCGATACAGGGGGG (ODN D 113, SEQ ID NO:15).

25

This oligodeoxynucleotide has a far flanking region that is not self-complementary and induces high levels of IFN-γ and IFN-α.

Another specific, non-limiting example of a D oligodeoxynucleotides is:

GGTGCGTCGATGCAGGGGGG (D28, SEQ ID NO:16).

5   This oligodeoxynucleotide is of use for inducing production and/or release of cytokines from immune cells, although it lacks a self-complementary motif.

In one embodiment, the D oligodeoxynucleotides disclosed herein are at least about 16 nucleotides in length. In a second embodiment, a D oligodeoxynucleotide is at least about 18 nucleotides in length. In another embodiment, a D

10   oligodeoxynucleotide is from about 16 nucleotides in length to about 100 nucleotides in length. In yet another embodiment, a D oligodexoynucleotide is from about 16 nucleotides in length to about 50 nucleotides in length. In a further embodiment, a D oligodeoxynucleotide is from about 18 nucleotides in length to about 30 nucleotides in length.

15   In another embodiment, the oligodeoxynucleotide is at least 18 nucleotides in length, and at least two G's are included at the 5' end of the molecule, such that the oligodeoxynucleotide includes a sequence represented by Formula IV:

$$5' \ GGX_1X_2X_3 \ Pu_1 \ Py_2 \ CpG \ Pu_3 \ Py_4 \ X_4X_5X_6(W)_M \ (G)_N\text{-}3'.$$

20   The D oligodeoxynucleotide can include additional G's at the 5' end of the oligodeoxynucleotide. In one specific example, about 1 or about 2 G's are included at the 5' end of an olgiodeoxynucleotide including a sequence as set forth as Formula IV.

Examples of a D oligodeoxynucleotide include, but are not limited to:

25   5'XXTGCATCGATGCAGGGGGG 3' (SEQ ID NO: 1)

             5'XXTGCACCGGTGCAGGGGGG3' (SEQ ID NO: 2),

             5'XXTGCGTCGACGCAGGGGGG3' (SEQ ID NO: 3),

             5'XXTGCGTCGATGCAGGGGGG3' (SEQ ID NO: 4),

             5'XXTGCGCCGGCGCAGGGGGG3' (SEQ ID NO: 5),

5'XXTGCGCCGATGCAGGGGGG3' (SEQ ID NO: 6),

5'XXTGCATCGACGCAGGGGGG3' (SEQ ID NO: 7),

5'XXTGCGTCGGTGCAGGGGGG3' (SEQ ID NO: 8),

wherein X is any base, or is no base at all. In one specific, non-limiting example, X

5   is a G. In particular, non-limiting examples, the oligodeoxynucleotide includes a

sequence selected from the group consisting of SEQ ID NO: 1, SEQ ID NO: 2, SEQ

ID NO: 3, SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 7, SEQ ID

NO: 8, SEQ ID NO: 9, SEQ ID NO: 10, SEQ ID NO: 11, SEQ ID NO: 12, SEQ ID

NO: 13, SEQ ID NO: 14, SEQ ID NO: 15, SEQ ID NO: 16, SEQ ID NO: 17, SEQ

10   ID NO: 18, SEQ ID NO: 21, SEQ ID NO: 22, SEQ ID NO: 23, SEQ ID NO: 24, and

SEQ ID NO: 25.

       The D and K oligodeoxynucleotides disclosed herein can be synthesized *de*

novo using any of a number of procedures well known in the art. For example, the

oligodeoxynucleotides can be synthesized as set forth in U.S. Patent No. 6,194,388,

15   which is herein incorporated by reference in its entirety. A D oligodeoxynucleotide

may be synthesized using, for example, by the B-cyanoethyl phosphoramidite

method or nucleoside H-phosphonate method. These chemistries can be performed

by a variety of automated oligonucleotide synthesizers available in the market.

Alternatively, oligodeoxynucleotides can be prepared from existing nucleic acid

20   sequences (e.g. genomic or cDNA) using known techniques, such as employing

restriction enzymes, exonucleases or endonucleases, although this method is less

efficient than direct synthesis.

B.   *Pharmaceutical Compositions*

25   The immunostimulatory ODNs described herein may be formulated in a

variety of ways depending on the location and type of disease to be treated or

prevented. Pharmaceutical compositions are thus provided for both local (e.g.

topical or inhalational) use and for systemic use. Therefore, the disclosure includes

within its scope pharmaceutical compositions comprising at least one

30   immunostimulatory ODN formulated for use in human or veterinary medicine.

While the immunostimulatory ODNs will typically be used to treat human subjects,

they may also be used to treat similar or identical diseases in other vertebrates, such other primates, dogs, cats, horses, and cows.

Pharmaceutical compositions that include at least one immunostimulatory K or D ODN as described herein as an active ingredient, or that include both an immunostimulatory ODN and an additional anti-infective agent as active ingredients, may be formulated with an appropriate solid or liquid carrier, depending upon the particular mode of administration chosen. Additional active ingredients include, for example, anti-infective agents, such as antibiotics, anti-fungal compounds, anti-viral compounds, and hyper-immune globulin. A suitable administration format may best be determined by a medical practitioner for each subject individually. Various pharmaceutically acceptable carriers and their formulation are described in standard formulation treatises, e.g., *Remington's Pharmaceutical Sciences* by E. W. Martin. See also Wang, Y. J. and Hanson, M. A., *Journal of Parenteral Science and Technology*, Technical Report No. 10, Supp. 42: 2S, 1988.

The dosage form of the pharmaceutical composition will be determined by the mode of administration chosen. For instance, in addition to injectable fluids, inhalational and oral formulations can be employed. Inhalational preparations can include aerosols, particulates, and the like. In general, the goal for particle size for inhalation is about 1 μm or less in order that the pharmaceutical reach the alveolar region of the lung for absorption. Oral formulations may be liquid (e.g., syrups, solutions, or suspensions), or solid (e.g., powders, pills, tablets, or capsules). For solid compositions, conventional non-toxic solid carriers can include pharmaceutical grades of mannitol, lactose, starch, or magnesium stearate. Actual methods of preparing such dosage forms are known, or will be apparent, to those of ordinary skill in the art.

In some embodiments, the bioavailability and duration of action of CpG ODN may improve their therapeutic efficacy. One potential method for protecting CpG ODN from degradation while increasing their uptake by cells of the immune system involves liposome encapsulation (MacDonald et al., *Biochim. Biophys. Acta* 1061:297, 1991; Takeshita et al., *Eur. J. Immunol.* 30:108, 2000). Sterically stabilized cationic liposomes (SSCL) compositions efficiently incorporate and

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deliver K type CpG ODNs to cells *in vitro* and *in vivo*. The SSCLs are liposomes
that include a cationic lipid, a colipid, and a stabilizing additive, as described below.

Cationic lipids include, but are not limited to spermidine-cholesterol,
spermine-cholesterol, is dimethylaminoethae-carbomol-chlesteroc (DC-CHOL), and
5   dioctadecylamidoglycylspermine (DOGS). In one embodiment, the cationic lipid is
dimethylaminoethane-carbomol-cholesterol (DC-CHOL). Colipids include, but are
not limited to, neutral, zwitterionic, and anionic lipids. In one embodiment, the
colipid is dioleoylphosphatidylethanolamine (DOPE). The colipid can be a moiety
that allows the stabilizing additive (see below) to be incorporated into the complex.
10   Without being bound by theory, derivatization of the lipid with an additive allows
the moiety to anchor the stabilizing additive to the cationic lipid complex. The
colipid can be conjugated to additives which prevent aggregation and precipitation
of cationic lipid-nucleic acid complexes. Colipids which may be used to incorporate
such additives to compositions disclosed herein include, but are not limited to,
15   zwitterionic or other phospholipids. Preferably, the colipid is inert and
biocompatible.

The ratio of cationic lipid to colipid (as a molar ratio) is from about 3:7 to
about 7:3. In one embodiment, the ratio of cationic lipid to colipid (molar ratio) is
about 4:6 to about 6:4. In a further embodiment, the lipid to colipid (molar ratio) is
20   about 4:6. Thus, in one specific, non-limiting example DC-CHOL and DOPE are
included in the sterically stabilized cationic liposome at a molar ratio of about 4:6.

Stabilizing agents are also included in the sterically stabilized cationic
liposomes. Without being bound by theory, it is believed that the stabilizing agent
maintains the integrity of the complex, maintains stability during sizing procedures,
25   and increases shelf life. In one embodiment, the additives are bound to a moiety
capable of being incorporated into or binding to the complex, for example, a colipid.
Such additives generally are selected from among hydrophilic polymers, which
include, but are not limited to, polyethylene glycol, polyvinylpyrrolidine,
polymethyloxazoline, polyethyl-oxazoline, polyhydroxypropyl methacrylamide,
30   polylactic acid, polyglycolic acid, and derivatized celluloses such as
hydroxymethylcellulose or hydroxyethylcellulose (see published PCT Application
No. WO 94/22429). Other stabilizing agents include, but are not limited to

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perfluorinated or partially fluorinated alkyl chains, fluorinated phospholipids, fatty
acids and perfluoroalkylated phospholipids and polyglucoronic acids (Oku et al.,
Critical Reviews in Therapeutic Drug Carrier Systems, 11:231-270, 1994).

A variety of methods are available for preparing liposomes as described in,

5   e.g., Szoka et al., *Ann. Rev. Biophys. Bioeng.* 9:467, 1980; U.S. Patent No.
4,186,183; U.S. Patent No. 4,217,344; U.S. Patent No. 4,235,871; U.S. Patent No.
4,261,975; U.S. Patent No. 4,485,054; U.S. Patent No. 4,501,728; U.S. Patent No.
4,774,085; U.S. Patent No.4,837,028; U.S. Patent No. 4,946,787; PCT Publication
No. WO 91/17424; Szoka & Papahadjopoulos, *Proc. Natl. Acad. Sci. USA* 75:4194-

10   4198, 1978; Deamer & Bangham, *Biochim. Biophys. Acta* 443:629-634, 1976;
Fraley *et al.*, *Proc. Natl. Acad. Sci. USA* 76:3348-3352, 1979; Hope et al., *Biochim.
Biophys. Acta* 812:55-65, 1985; Mayer et al., *Biochim. Biophys. Acta* 858:161-168,
1986; Williams et al., *Proc. Natl. Acad. Sci. USA* 85:242-246, 1988, Liposomes, ch.
1 (Ostro, ed., 1983); and Hope *et al.*, *Chem. Phys. Lip.* 40:89, 1986; U.S. Patent No.

15   6,410,049. Suitable methods include, e.g., sonication, extrusion, high
pressure/homogenization, microfluidization, detergent dialysis, calcium-induced
fusion of small liposome vesicles, and ether-infusion methods, all well known in the
art.

In one embodiment, a pharmacological composition is provided that includes

20   a D or K oligonucleotide and a pharmacologically acceptable carrier.
Pharmacologically acceptable carriers (e.g., physiologically or pharmaceutically
acceptable carriers) are well known in the art. A suitable pharmacological
composition can be formulated to facilitate the use of K or D type ODN *in vivo*.
Such a composition can be suitable for delivery of the active ingredient to any

25   suitable host, such as a patient for medical application, and can be manufactured in a
manner that is itself known, e.g., by means of conventional mixing dissolving,
granulating, dragee-making, levigating, emulsifying, encapsulating, entrapping, or
lyophilizing processes.

The compositions or pharmaceutical compositions can be administered by

30   any route, including parenteral administration, for example, intravenous,
intraperitoneal, intramuscular, intraperitoneal, intrasternal, or intra-articular injection
or infusion, or by sublingual, oral, topical, intra-nasal, or transmucosal

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administration, or by pulmonary inhalation. When immunostimulatory ODNs are

provided as parenteral compositions, e.g. for injection or infusion, they are generally

suspended in an aqueous carrier, for example, in an isotonic buffer solution at a pH

of about 3.0 to about 8.0, preferably at a pH of about 3.5 to about 7.4, 3.5 to 6.0, or

5   3.5 to about 5.0. Useful buffers include sodium citrate-citric acid and sodium

phosphate-phosphoric acid, and sodium acetate/acetic acid buffers.

       For oral administration, the pharmaceutical compositions can take the form

of, for example, tablets or capsules prepared by conventional means with

pharmaceutically acceptable excipients such as binding agents (e.g., pregelatinised

10   maize starch, polyvinylpyrrolidone or hydroxypropyl methylcellulose); fillers (e.g.,

lactose, microcrystalline cellulose or calcium hydrogen phosphate); lubricants (e.g.,

magnesium stearate, talc or silica); disintegrants (e.g., potato starch or sodium starch

glycolate); or wetting agents (e.g., sodium lauryl sulphate). The tablets can be

coated by methods well known in the art. Liquid preparations for oral

15   administration can take the form of, for example, solutions, syrups or suspensions,

or they can be presented as a dry product for constitution with water or other suitable

vehicle before use. Such liquid preparations can be prepared by conventional means

with pharmaceutically acceptable additives such as suspending agents (e.g., sorbitol

syrup, cellulose derivatives or hydrogenated edible fats); emulsifying agents (e.g.,

20   lecithin or acacia); non-aqueous vehicles (e.g., almond oil, oily esters, ethyl alcohol

or fractionated vegetable oils); and preservatives (e.g., methyl or propyl-p-

hydroxybenzoates or sorbic acid). The preparations can also contain buffer salts,

flavoring, coloring, and sweetening agents as appropriate.

       For administration by inhalation, the compounds for use according to the

25   present invention are conveniently delivered in the form of an aerosol spray

presentation from pressurized packs or a nebulizer, with the use of a suitable

propellant, e.g., dichlorodifluoromethane, trichlorofluoromethane,

dichlorotetrafluoroethane, carbon dioxide or other suitable gas. In the case of a

pressurized aerosol, the dosage unit can be determined by providing a valve to

30   deliver a metered amount. Capsules and cartridges for use in an inhaler or

insufflator can be formulated containing a powder mix of the compound and a

suitable powder base such as lactose or starch.

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Pharmaceutical compositions that comprise an immunostimulatory ODN as described herein as an active ingredient will normally be formulated with an appropriate solid or liquid carrier, depending upon the particular mode of administration chosen. The pharmaceutically acceptable carriers and excipients of

5   use are conventional. For instance, parenteral formulations usually comprise injectable fluids that are pharmaceutically and physiologically acceptable fluid vehicles such as water, physiological saline, other balanced salt solutions, aqueous dextrose, glycerol or the like. Excipients that can be included are, for instance, proteins, such as human serum albumin or plasma preparations. If desired, the

10   pharmaceutical composition to be administered may also contain minor amounts of non-toxic auxiliary substances, such as wetting or emulsifying agents, preservatives, and pH buffering agents and the like, for example sodium acetate or sorbitan monolaurate. Actual methods of preparing such dosage forms are known, or will be apparent, to those skilled in the art.

15   For example, for parenteral administration, immunostimulatory ODNs can be formulated generally by mixing them at the desired degree of purity, in a unit dosage injectable form (solution, suspension, or emulsion), with a pharmaceutically acceptable carrier, i.e., one that is non-toxic to recipients at the dosages and concentrations employed and is compatible with other ingredients of the

20   formulation. A pharmaceutically acceptable carrier is a non-toxic solid, semisolid or liquid filler, diluent, encapsulating material or formulation auxiliary of any type.

Generally, the formulations are prepared by contacting the immunostimulatory ODNs each uniformly and intimately with liquid carriers or finely divided solid carriers or both. Then, if necessary, the product is shaped into

25   the desired formulation. Optionally, the carrier is a parenteral carrier, and in some embodiments it is a solution that is isotonic with the blood of the recipient. Examples of such carrier vehicles include water, saline, Ringer's solution, and dextrose solution. Non-aqueous vehicles such as fixed oils and ethyl oleate are also useful herein, as well as liposomes.

30   The pharmaceutical compositions that comprise an immunostimulatory ODN, in some embodiments, will be formulated in unit dosage form, suitable for individual administration of precise dosages. The amount of active compound(s)

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administered will be dependent on the subject being treated, the severity of the affliction, and the manner of administration, and is best left to the judgment of the prescribing clinician. Within these bounds, the formulation to be administered will contain a quantity of the active component(s) in amounts effective to achieve the

5   desired effect in the subject being treated.

The therapeutically effective amount of immunostimulatory ODN will be dependent on the ODN utilized, the subject being treated, the severity and type of the affliction, and the manner of administration. For example, a therapeutically effective amount of immunostimulatory ODN can vary from about 0.01 µg per

10   kilogram (kg) body weight to about 1 g per kg body weight, such as about 1 µg to about 5 mg per kg body weight, or about 5µg to about 1 mg per kg body weight. The exact dose is readily determined by one of skill in the art based on the potency of the specific compound (such as the immunostimulatory ODN utilized), the age, weight, sex and physiological condition of the subject.

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C.   *Therapeutic Uses*

Methods are disclosed herein for treating or preventing an infection in a subject who has been exposed to or is at risk for exposure to a bioterrorism agent. These methods include:

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1. administering a therapeutically effective amount of the immunostimulatory ODN to a subject who has been exposed to or is at risk for exposure to a bioterrorism agent,

2. administering a therapeutically effective amount of the

25   immunostimulatory ODN in combination with an anti-infective agent to a subject who has been exposed to or is at risk for exposure to a bioterrorism agent, thereby treating or preventing the infection in a subject, and

3. administering to the subject a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide or an immunostimulatory K

30   oligodeoxynucleotide in combination with a vaccine against a bioterrorism agent.

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Bioterrorism agents include, but are not limited to *Bacillus anthracis,*
Yersinia pestis, Variola major, Histoplasma capsulatum, Haemophilus influenzae,
Ebola virus, tick-borne encephalitis virus (TBEV), *Escherichia coli, Shigella*
flexneri, S. dysenteriae (Shigella bacillus), Salmonella, Staphylococcus enterotoxin

5   B, botulinum toxin, ricin toxin, cobra venom, shellfish toxin, botulinum toxin,
saxitoxin, ricin toxin, tricothecene mycotoxin, or aflatoxin. Exposure to
bioterrorism agents can result in infections, such as, but not limited to, anthrax,
cryptococcosis, brucellosis, coccidioidomycosis, psittacosis, bubonic plague,
tularemia, malaria, cholera, typhoid, hemorrhagic fever, tick-borne encephalitis,

10   Venezuelan equine encephalitis, pneumonic plague, Rocky Mountain spotted fever,
dengue fever, Rift Valley fever, diphtheria, melioidosis, glanders, tuberculosis,
infectious hepatitis, encephalitides, blastomycosis, nocardiosis, yellow fever, typhus,
or Q fever.

Some embodiments of the methods include administering a therapeutically

15   effective amount of the immunostimulatory ODN to a subject who has been exposed
to or is at risk for exposure to a bioterrorism agent, thereby treating or preventing the
infection in a subject. Without being bound by theory, administration of the
immunostimulatory ODN increases the general immune activation, leading to an
increase in the immune response to the bioterrorism agent or vaccine. In this

20   manner, a subject can be at reduced risk of infection or susceptible to fewer
symptoms, and can obtain further treatment if necessary. In one embodiment, the
immunostimulatory ODN can be administered locally, such as by inhalation. In
another embodiment, the immunostimulatory ODN is administered systemically,
such as by intravenous injection, intramuscular injection, or subcutaneous injection.

25   In some embodiments, the immunostimulatory ODN is administered to the
subject prior to exposure to a bioterrorism agent, for example, two weeks, one week,
one day, six hours, or one hour prior to exposure. The immunostimulatory ODN can
also be administered to the subject after exposure to a bioterrorism agent, for
example, two weeks, one week, one day, six hours, or one hour after exposure. In

30   some embodiments, the immunostimulatory ODN is administered to a subject who
is at risk for exposure to a bioterrorism agent, for example, a member of the military,
a police officer, a mail handler, a government official, or any other individual who is

at risk for exposure to a bioterrorism agent. For example, in one specific, non-limiting example, an immunostimulatory ODN is administered to a member of the military three days, six days, or two weeks before deployment. Suitable subjects also include those who are more prone to illness following bioterrorism agent

5   exposure, such as subjects with weakened immune systems, for example, the elderly, people on immunosuppressive drugs, subjects with cancer, and subjects infected with HIV

Combinations of these immunostimulatory ODNs are also of use. Thus, in one embodiment, more than one immunostimulatory D or K ODN, or both D and K

10   ODNs, each with a different nucleic acid sequence, are administered to the subject. In several specific, non-limiting examples, at least two, at least three, or at least four immunostimulatory D ODNs are administered to the subject. In other specific, non-limiting examples, at least two, at least three, or at least four immunostimulatory K ODNs are administered to the subject. In still further specific, non-limiting

15   examples, at least two, at least three, or at least four immunostimulatory D ODNs are administered to the subject in combination with at least two, at least three, or at least four immunostimulatory K ODNs.

An effective amount of an immunostimulatory ODN can be administered in a single dose, or in multiple doses, for example weekly, during a course of treatment.

20   In one embodiment, a therapeutically effective amount of an immunostimulatory ODN is administered as a single pulse dose, as a bolus dose, or as pulse doses administered over time. Thus, in pulse doses, a bolus administration of an immunostimulatory ODN is provided, followed by a time period wherein no immunostimulatory ODN is administered to the subject, followed by a second bolus

25   administration. In specific, non-limiting examples, pulse doses of an immunostimulatory ODN are administered during the course of a day, during the course of a week, or during the course of a month.

Thus, the immunostimulatory ODNs disclosed herein may be administered to a subject for the treatment of a bioterrorism agent-induced infection in that

30   individual. ODN administration can be systemic or local. Local administration of the ODN is performed by methods well known to those skilled in the art. By way of example, one method of administration to the lungs of an individual is by inhalation

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through the use of a nebulizer or inhaler. For example, the ODN is formulated in an aerosol or particulate and drawn into the lungs using a standard nebulizer well known to those skilled in the art.

In other embodiments, the administration of the immunostimulatory ODN is
5 systemic. Oral, intravenous, intra-arterial, subcutaneous, intra-peritoneal, intra-muscular, and even rectal administration is contemplated. Prevention of an infection includes both prevention of symptoms and delaying the onset of symptoms. In specific, non-limiting examples, administration of an immunostimulatory ODN delays symptoms of an infection until further treatment is sought.

10   The effectiveness of treatment with an immunostimulatory ODN can be measured by monitoring symptoms of infection, for example, fever. For example, a decrease in fever over time is an indicator of efficacy of ODN treatment.

        In some embodiments, the method includes administering to the subject an anti-infective agent, such as an antibiotic, anti-viral compound, anti-fungal
15 compound, or hyper-immune globulin, in conjunction with an immunostimulatory ODN. The administration of the additional anti-infective agent and the immunostimulatory ODN can be sequential or simultaneous.

        Anti-infectious agents include, but are not limited to, anti-fungal compounds, anti-viral compounds, and antibiotics. Antibiotics include, but are not limited to,
20 amoxicillin, clarithromycin, cefuroxime, cephalexin ciprofloxacin, doxycycline, metronidazole, terbinafine, levofloxacin, nitrofurantoin, tetracycline, and azithromycin. Anti-fungal compounds, include, but are not limited to, clotrimazole, butenafine, butoconazole, ciclopirox, clioquinol, clioquinol, clotrimazole, econazole, fluconazole, flucytosine, griseofulvin, haloprogin, itraconazole, ketoconazole,
25 miconazole, naftifine, nystatin, oxiconazole, sulconazole, terbinafine, terconazole, tioconazole, and tolnaftate. Anti-viral compounds, include, but are not limited to, zidovudine, didanosine, zalcitabine, stavudine, lamivudine, abacavir, tenofovir, nevirapine, delavirdine, efavirenz, saquinavir, ritonavir, indinavir, nelfinavir, saquinavir, amprenavir, and lopinavir. Anti-infectious agents also include hyper-
30 immune globulin.

        Other methods described herein are methods of enhancing the immunogenicity of a vaccine against a bioterrorism agent in a subject. In some

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embodiments, the vaccine against a bioterrorism agent is an antigen. The method includes administering to the subject a therapeutically effective amount of an immunostimulatory D oligodeoxynucleotide or an immunostimulatory K oligodeoxynucleotide in combination with a vaccine against a bioterrorism agent,

5   thereby enhancing the efficacy of the vaccine. The vaccine can be a preparation of antigen, DNA, protein subunit, peptide, attenuated microorganisms (including but not limited to bacteria and viruses), living microorganisms, or killed microorganisms, administered for the prevention, amelioration or treatment of a disease caused by a bioterrorism agent.

10   In some embodiments, the vaccine is a heat or formalin-killed vaccine. Examples of heat-killed vaccines in common use today are the typhoid vaccine and the Salk poliomyelitis vaccine.

In other embodiments, the vaccine is an acellular vaccine. Acellular vaccines are made using only the antigenic part of the disease-causing organism, for

15   example the capsule, the flagella, or part of the protein cell wall. In still other embodiments, the vaccine is an attenuated vaccine. Attenuated vaccines are made by "attenuating" or weakening a live microorganism by aging it or altering its growth conditions. In still further embodiments, the vaccine is a toxoid.

In other embodiments, the vaccine is made from a related, less virulent

20   pathogen. The related pathogen does not cause serious disease, but provides protection from the more virulent pathogen. For example, the relatively mild cowpox virus is used to protect against the similar, but often lethal, smallpox virus. In still further embodiments, the vaccine is a subunit vaccine or a DNA vaccine.

Thus, a CpG oligonucleotide can be used in conjunction with a wide variety

25   of vaccines against a bioterrorism agent, including but not limited to, a heat or formalin-killed vaccine, attenuated vaccine, protein subunit vaccine, antigen vaccine, DNA vaccine, acellular vaccine, or toxoid vaccine directed against *Bacillus anthracis, Yersinia pestis, Variola major*, tick-borne encephalitis virus (TBEV), Ebola virus, *Escherichia coli, Haemophilus influenzae*, cobra venom, shellfish toxin,

30   botulinum toxin, saxitoxin, ricin toxin, *Shigella flexneri, S. dysenteriae (Shigella bacillus), Salmonella, Staphylococcus* enterotoxin B, *Histoplasma capsulatum*, tricothecene mycotoxin, aflatoxin. The vaccine can also be directed against

cryptococcosis, brucellosis (undulant fever), coccidioidomycosis (San Joaquin
Valley or desert fever), psittacosis (parrot fever), bubonic plague, tularemia (rabbit
fever), malaria, cholera, typhoid, hemorrhagic fever, tick-borne encephalitis,
Venezuelan equine encephalitis, pneumonic plague, Rocky Mountain spotted fever,
5   dengue fever, Rift Valley fever, diphtheria, melioidosis, glanders, tuberculosis,
infectious hepatitis, encephalitides, blastomycosis, nocardiosis, yellow fever, typhus,
and Q fever. In some embodiments, the vaccine is an antigen from *Bacillus
anthracis*, Ebola virus, tick-borne encephalitis virus (TBEV), *Yersinia pestis*,
Variola major, *Histoplasma capsulatum*, *Haemophilus influenzae*, *Escherichia coli*,
10   *Shigella flexneri*, *S. dysenteriae* (*Shigella bacillus*), *Salmonella*, or *Staphylococcus*.

       In particular examples of certain embodiments, the vaccine is an anthrax
vaccine, such as, but not limited to AVA, or an anthrax antigen, such as, but not
limited to Protective Antigen (PA) or recombinant Protective Antigen (rPA).

       Primary vaccination with AVA generally consists of three subcutaneous
15   injections at 0, 2, and 4 weeks, and three booster vaccinations at 6, 12, and 18
months. To maintain immunity, the manufacturer recommends an annual booster
injection. Because of the complexity of a six-dose primary vaccination schedule and
frequency of local injection-site reactions, schedules with a reduced number of doses
would be desirable. Administration of AVA in conjunction with an
20   immunostimulatory D or K ODN provides a better immune response to the vaccine
than use of the vaccine alone, and can result in a decreased frequency of
immunizations required to attain an immune protective response.

       In particular, non-limiting examples, the vaccine is a DNA sequence
encoding the non-toxic protective antigen (PA) from *B. anthracis* or an
25   immunogenic fragment thereof. The sequence for PA has been determined and has
been deposited in GenBank at Accession No. M22589. Other antigens of use
include, but are not limited to, *B. anthracis* lethal factor (LF) or an immunogenic
fragment thereof, disclosed in U.S. Publication No. US 2002/0051791A1, hantavirus
antigens, for example those disclosed in U.S. Patent No. 5,614,193, smallpox
30   antigens, for example those disclosed in U.S. Patent No. 4,567,147, plague antigens,
for example those disclosed in WO 98/24912 A2, Ebola virus antigens, for example
those disclosed in WO 00/00617A2, tick-borne encephalitis antigens, for example

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those disclosed in U.S. Patent No. 6,372,221 and EP 0691404 B1, *Histoplasma capsulatum* antigens, for example those disclosed in WO 99/55874A2 and U.S. Patent No. 6,391,313, *Haemophilus influenzae* antigens, for example those disclosed in U.S. Patent No. 6,342,232, EP 0432220 B1, and U.S. Patent No. RE 37741, *E.*

5   *coli* antigens, for example those disclosed in U.S. Patent No. 5,370,872, U.S. Patent No. 6,077,516, and U.S. Patent No. 3,975,517, *Shigella* antigens, for example those disclosed in U. S. Patent No. 5,077,044, U.S. Patent No. 5,686,580, and U.S. Patent No. 5,681,736, *Salmonella* antigens, for example those disclosed in WO 01/70247 A2, U.S. Publication No. 2001/0021386A1 and EP 1112747A1, and

10   *Staphylococcus* antigens, for example those disclosed in EP 0694309A3 and U.S. Patent No. 6,391,315.

The method includes administering a therapeutically effective amount of the immunostimulatory D and/or K ODN to a subject in conjunction with a vaccine against a bioterrorism agent, thereby enhancing the immunogenicity of the vaccine.

15   In one embodiment, the immunostimulatory ODN can be administered locally, such as topically or by inhalation. In another embodiment, the immunostimulatory ODN is administered systemically, such as by intravenous injection, intramuscular injection, or subcutaneous injection.

Combinations of immunostimulatory ODNs are also of use in enhancing the

20   immunogenicity of a vaccine against a bioterrorism agent. Thus, in one embodiment, more than one immunostimulatory ODN, each with a different nucleic acid sequence, are administered to the subject in combination with the vaccine. In several specific, non-limiting examples, at least two, at least three, or at least four immunostimulatory ODNs are administered to the subject in combination with the

25   vaccine.

An effective amount of an immunostimulatory ODN can be administered in combination with a vaccine against a bioterrorism agent in a single dose, or in multiple doses. For example, in some embodiments, boosters of the vaccine and immunostimulatory ODN can be administered periodically after the initial

30   administration, for example, at one month, two months, or three months after the initial administration. In specific, non-limiting examples, pulse doses of an immunostimulatory ODN, in combination with a vaccine against a bioterrorism

agent, are administered at 2 weeks, 4 weeks, 6 months, 12 months, 18 months, or yearly after the initial bolus administration.

In other embodiments, a subject who likely has been exposed to a bioterrorism agent can receive a vaccine against a bioterrorism agent in conjunction

5   with an immunostimulatory D or K ODN and an anti-infective agent. For example, during a course of treatment of a suspect who has been, or is likely to have been exposed to a bioterrorism agent, the vaccine and ODN can be administered daily, weekly, or every two weeks.

The immunostimulatory ODNs can be administered before vaccine

10   administration, concurrently with vaccine administration or after vaccine administration. For example, the immunostimulatory ODN can be administered before the vaccine is administered, for instance, two weeks, one week, one day, or one hour before the vaccine is administered to the subject. Alternatively, the immunostimulatory ODN can be administered concurrently with vaccine

15   administration, or, for instance, two weeks, one week, one day, or one hour after the vaccine is administered to the subject.

Thus, the immunostimulatory ODNs described herein can be administered to a subject in combination with a vaccine against a bioterrorism agent in order to enhance the immunogenicity of the vaccine. The effectiveness of the ODN

20   administration can be measured by monitoring vaccine against a bioterrorism agent titer or avidity of antibody response, or cytotoxic T cell response, by methods known to one of skill in the art. For example, an increase in vaccine against a bioterrorism agent titer or avidity of antibody response over time is an indicator of efficacy of ODN treatment.

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The disclosure is illustrated by the following non-limiting Examples.

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EXAMPLES

Example 1

Materials and Methods

Reagents

5   Phosphorothioate ODN (Table 1) were synthesized or obtained from a

commercial source. Specifically, CpG 7909 and CpG 10103 are both K type ODN

that were obtained from Coley Pharmaceuticals (Wellesley, MA). All synthesized

ODN had less than <0.1 EU of endotoxin per mg of ODN as assessed by a Limulus

amebocyte lysate assay (QCL-1000, BioWhittaker).

10   AVA was obtained from BioPort Corporation (East Lansing, MI).

Recombinant PA (rPA) was produced as previously described (Farchaus et al., *Appl.*

Environ. Microbiol. 64:982, 1998). For vaccinations, 50 µg of rPA was dissolved in

0.5 ml of PBS plus 0.5 mg of aluminum. (Alhydrogel, SuperFos/BioSector,

Denmark).

15   The *Bacillus anthracis* Ames and Vollum 1B strains were obtained from the

culture collection of the United States Army Medical Research Institute of Infectious

Diseases, Fort Detrick, MD. Spores were prepared and stored as previously

described (Ivins et al., *Infect. Immun.* 58:303, 1990).

20   **Table 1   Sequence and backbone of murine and human ODN**

Species	Designation	SEQ ID NO:	Sequence
Mouse	CpG ODN 1555	SEQ ID NO: 17	GCTAGA<u>CG</u>TTAGCGT
Mouse	CpG ODN 1466	SEQ ID NO: 18	TCAA<u>CG</u>TTGA
Mouse	Control ODN	SEQ ID NO: 19	GCTAGAGCTTAGGCT
Mouse	Control ODN	SEQ ID NO: 20	TCAAGCTTGA
Human	CpG ODN D19	SEQ ID NO: 21	*GG*TGCAT<u>CG</u>ATGCAGG*GGGG*
Human	CpG ODN D29	SEQ ID NO: 22	*GG*TGCAC<u>CG</u>GTGCAGG*GGGG*
Human	CpG ODN D35	SEQ ID NO: 21	*GG*TGCAT<u>CG</u>ATGCAGGGG*GG*
Human	CpG ODN K3	SEQ ID NO: 23	AT<u>CG</u>ACTCT<u>CG</u>AGC<u>CG</u>TTCTC
Human	CpG ODN K123	SEQ ID NO: 24	T<u>CG</u>TT<u>CG</u>TTCTC
Human	CpG ODN K23	SEQ ID NO: 25	T<u>CG</u>AGC<u>CG</u>TTCTC
Human	Control ODN	SEQ ID NO: 26	GGTGCAT<u>T</u>GATGCAGGGGGG
Human	Control ODN	SEQ ID NO: 27	TTGAGTGTTCTC
Human	Control ODN	SEQ ID NO: 28	GGGCATGCATGGGGGG

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Bases shown in italics are phosphodiester while all others are
phosphorothioate. CpG dinucleotides are underlined.

5   *Animals*

All animal studies were ACUC approved and were conducted in AAALAC
accredited facilities. Animals were monitored daily by veterinarians. Specific
pathogen-free BALB/c mice were obtained from the Jackson Laboratories (Bar
Harbor, ME) and housed in sterile micro-isolator cages in a barrier environment.

10   Mice were injected i.p. at 6-8 weeks of age with 50 µg of CpG ODN and then
challenged SQ with 11 - 70 LD50 *B. anthracis* Vollum 1B spores.

Hartley guinea pigs, 325-375 gm (Charles River) were immunized IM with
0.5 ml-doses of AVA plus 100 - 300 µg of CpG ODN, and boosted with the same
material 4 weeks later. Animals were challenged IM at week 10 with 5,000 (50

15   LD50) Ames spores.

Healthy 3 year old female rhesus macaques were obtained from the FDA
colony in South Carolina. Five to six animals/group were immunized
subcutaneously at 0 and 6 weeks with the normal human dose of AVA (0.5 ml) or
rPA (50 µg) plus 250 µg of "K" or "D" CpG ODN. Animals were "challenged" IM

20   with the live veterinary vaccine strain of anthrax (Sterne) on week 27. Treatments
were administered and peripheral blood samples obtained from ketamine
anesthetized animals (10 mg/kg, Ketaject, Phoenix Pharmaceuticals, St. Joseph,
MD).

For several of the experiments, five groups of 5 male and female rhesus

25   macaques/group were immunized subcutaneously (SQ) or intramuscularly (IM) on
study days 0 and 42 with 0.5 mL of AVA plus 0 or 250 µg of CpG ODN. All
animals were monitored daily by veterinarians. Treatments were administered under
appropriate anesthesia. A baseline blood sample was collected from each non-human
primate (NHP) 10 days before the first injection (study day –10). Blood was

30   collected from each NHP on days 1, 4, 11, 16, 21, 28, 35, 42, 49, 56, and 63 after the
first injection.

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Anti-PA ELISA and avidity assays

      The titer of IgG against the anthrax PA was monitored by enzyme linked immunosorbent assay (ELISA). Anti-PA IgG is considered a marker of vaccine efficacy as anti-PA antibodies confer protection to host cells by blocking the binding

5   of anthrax toxin (see Pittman et al., *Vaccine* 20:1412-1420, 2002). Anti-PA antibodies also inhibit spore germination and increase the uptake and elimination of spores by macrophages (Welkos et al., *Microbiology* 147:1677-1685, 2001). The titer of anti-PA IgM was also evaluated by ELISA to evaluate any differences in the immunogenicity of the vaccine and adjuvant combinations.

10   Microtiter plates (96-well Immulon 2; Dynex Technologies Inc., Chantilly, VA) were coated with 1 μg/ml of rPA in PBS and then blocked with PBS - 5% non-fat milk and dried overnight. Serum samples diluted in blocking buffer were incubated on rPA-coated microtiter plates for 2 hours. After coating, plates were blocked with 0.1 % Tween 20 with 2% non-fat dry milk in PBS for one hour at room

15   temperature. Plates were then overlaid with serially diluted serum for 1 hour at 37°C as described (Ivins et al., *Infect Immun* 60, 662-668, 1992). The plates were washed, and bound antibody detected using peroxidase-conjugated goat anti-monkey IgG or IgM (Kirkegaard & Perry, Gaithersburg, MD) followed by ABTS substrate (Kirkegaard & Perry). Antibody titers were determined by comparison to a standard

20   curve generated using high-titered anti-PA serum. All samples were analyzed in triplicate. All assays were performed the same day using the same reagents for all plates.

      For avidity studies, the plates were washed, and were treated for 15 minutes with 200 μl of 6M urea. Bound antibodies were detected by adding peroxidase-

25   labeled goat anti-monkey IgG (Kirkegaard & Perry Laboratories, Gaithersburg, MD) followed by ABTS (Kirkegaard & Perry Laboratories). Titers were determined by comparison to a standard curve generated using high-titered anti-serum. All samples were analyzed in triplicate.

30   *TNA Assay*

      The TNA assay evaluates the ability of the test serum to neutralize the cytotoxic effects of anthrax lethal toxin (a mixture of PA and anthrax lethal factor

43

(LF)) in an *in vitro* assay. A murine target cell line susceptible to anthrax lethal toxin is incubated with mixtures of lethal toxin with control sera or lethal toxin with test sera. Percent cytotoxicity is determined by the addition of a colorimetric substrate, MTT, that in turn is hydrolyzed by the remaining viable cells into a purple

5   formazan precipitate, which is solubilized and quantitated on a plate reader. The effective dose 50 (ED_{50}) is calculated as the reciprocal of the dilution of test serum at which 50% neutralization of the lethal toxin is achieved. The concentration of neutralizing antibody is calculated using the ratio of the ED_{50} of the test serum compared to the ED_{50} of a standard reference serum.

10

Mouse Seroprotection Assay

Serum samples collected for the immunogenicity assays described above were stored frozen at -80°C until use. Equal volumes of serum from all animals in each treatment group from study day 11 and separately from study day 16 were

15   pooled. 100 μl of this serum pool was injected IV into 6 week old, male A/JCr mice (10 recipients/group). Twenty-four hours later, blood was collected from the tail vein from a subset of these animals (4-total) to assess serum IgG anti-PA titers. All mice were then challenged i.p. with 30-60 LD_{50} of Sterne strain anthrax spores diluted in 500 μl of PBS. Survival of these mice was monitored daily for 3 weeks,

20   and the time to death recorded. No mortality was observed in any group after day 10. The experiment was conducted twice.

Statistical analysis

Challenge experiments were performed using a minimum of 5-10

25   mice/group. Survival differences were evaluated using Student's t test, while differences in serum anti-PA Ab titers (or avidity) were evaluated by multiple regression ANOVA.

Example 2

30   **Immunoprotective activity of CpG ODN**

The ability of CpG ODN to improve the survival of normal BALB/c mice challenged with *B. anthracis* Vollum 1B spores was demonstrated. The fraction of

44

BALB/c mice surviving infection, and/or their mean time to death (MTD), was significantly improved by CpG ODN treatment 3 - 6 days prior to challenge (Table II). The earlier treatment was initiated, the greater the beneficial effect, consistent with the hypothesis that CpG motifs stimulate an immune cascade that matures over several days and then persists for several weeks (Elkins et al., *J. Immunol.* 162:2291, 1999; Klinman et al., *Immunity* 11:123, 1999). A modest prolongation in mean time to death (MTD) was observed in mice treated with CpG ODN one day prior to challenge, while treatment at the same time or after pathogen exposure had no effect on survival (Table II).

Table II Effect of CpG ODN on the survival of mice challenged with anthrax

	Experiment 1			Experiment 2
Treatment	Day	% survival	MTD	% survival
MTD				
CpG ODN	-6	50*	120	
CpG ODN	-3	0	110	20
114				
CpG ODN	0	0	98	
CpG ODN	1	0	89	
No Rx	0	98	0	96

BALB/c mice (N=10/group) were treated with 50 - 100 μg of CpG D ODN on the day shown, and infected with 70 (Exp 1) or 11 (Exp 2) *B. anthracis* 1B spores on Day 0. Survival and mean time to death (MTD in hours) is shown.

* Significantly improved survival compared to untreated mice, $p < .05$.

Thus, these CpG ODN can significantly reduce the mortality of mice infected with anthrax. Although 100% survival was not achieved, the mean time to death (MTD) was consistently prolonged, thus providing a "window of opportunity" to initiate life-saving antibiotic therapy. The activity of the ODN was unambiguously attributed to their CpG content, since control ODN in which the CpG dinucleotide was inverted to a GpC provided no protection.

45

Example 3

CpG ODN as vaccine adjuvants

Since exposure to anthrax is rarely predictable, the possibility that CpG ODN

5   could be used to enhance the immunogenicity of protective vaccines was

demonstrated. Due to evolutionary divergence in CpG recognition between species,

CpG motifs that are highly active in rodents are poorly immunostimulatory in

primates, and vice versa (Bauer et al., *Immunology* 97:699, 1999; Hartmann and

Krieg, *J. Immunology* 164:944, 2000; Verthelyi et al., *J. Immunol.* 166:2372, 2001).

10   Thus, primate models are optimal for examining the activity of CpG ODN being

developed for human use. Immune cells from rhesus macaques respond to the same

two classes of ODN that stimulate human cells (Streilein et al., *Immunol. Today*

18:443, 1997). "D" type ODN trigger primate cells to secrete IFN-α and IFNg and

promote the functional maturation of APC , whereas "K" type ODN induce immune

15   cells to proliferate and secrete IL-6 and/or IgM (Verthelyi et al., *J. Immunol.*

166:2372, 2001).

Mixtures of K and D ODN that strongly stimulate PBMC from both humans

and macaques (Streilein et al., *Immunol. Today* 18:443, 1997) were co-administered

as adjuvants with the licensed AVA vaccine and with the rPA vaccine currently

20   undergoing clinical evaluation. As seen in Fig 1, K ODN significantly increased the

maximum, average, and long-term IgG anti-PA responses. Over the duration of

study, K ODN increased the GMT of vaccinated macaques by 2.1 + 0.3 fold (p

<.03).

The quality of a vaccine-adjuvant combination is reflected by both the

25   avidity and titer of the resultant Ab response. The avidity of the IgG anti-PA Abs

elicited by AVA or rPA vaccination was monitored by incubating bound serum Abs

with 6 M urea. This treatment selectively elutes low avidity Abs (Eggers et al., *J.*

Med. Virol. 60:324, 2000; Cozon et al., *Eur. J. Clin. Microbiol. Infect. Dis.* 17:32,

1998). As seen in Fig 2, nearly 90% of the serum Abs generated by primary

30   vaccination with AVA were eluted by urea treatment. By comparison, <50% of the

serum anti-PA Abs present in animals boosted with AVA and then challenged with

attenuated anthrax could be eluted, consistent with affinity maturation of the memory response.

There was little difference in the average avidity of the serum anti-PA response of macaques initially immunized with AVA or rPA plus CpG ODN.

5   However, the use of K and D ODN as adjuvants generated Abs of significantly higher avidity post boost when compared to animals immunized and boosted with vaccine alone (p <.02).

Since CpG motifs that activate human immune cells tend to be weakly immunostimulatory in mice, their adjuvant effects are best assessed in non-human

10   primates. Fortunately, rhesus macaques respond to the same CpG motifs that stimulate human PBMC (Verthelyi et al., *J. Immunol.* 168:1659, 2002). When co-administered with the AVA vaccine, K ODN (which support B cell activation) significantly increased both the titer and avidity of the IgG anti-PA antibody response (Figs. 1 and 3). When "challenged" with a non-lethal strain of anthrax,

15   macaques immunized with AVA or rPA plus K ODN mounted stronger and longer lasting immune responses (Fig 1).

Additional studies were performed using two K type ODNs, ODN 7909 and ODN 10103. For these studies, five groups of 5 male and female rhesus macaques/group were immunized subcutaneously (SQ) or intramuscularly (IM) on

20   study days 0 and 42 with 0.5 mL of AVA plus 0 or 250 μg of CpG ODN. All animals were monitored daily by veterinarians. Treatments were administered under appropriate anesthesia. A baseline blood sample was collected from each non-human primate (NHP) 10 days before the first injection (study day –10). Blood was collected from each NHP on days 1, 4, 11, 16, 21, 28, 35, 42, 49, 56, and 63 after the

25   first injection.

The geometric means of the anti-PA IgG titer of the five vaccination groups for each day were computed. Anti-PA IgG titers for each animal on each serum collection day are shown in Appendix III. The area under the curve (AUC), Tmax and Cmax, for 3 different intervals were also computed as follows:

30   1. The entire study period up through Day 63 after the first vaccination.

2. The study period up through Day 42, which includes only data prior to the second vaccination.

47

3. The study period up through Day 21, to more closely assess the early titer

response.

AUC was calculated using the trapezoidal rule. Tmax is the time (days after

first vaccination) that the animal had the maximum anti-PA IgG titer during the

5   given time period, and Cmax is the anti-PA IgG on that day.

Table III shows the median and mean values for the AUC, Tmax, and Cmax

for each of the 3 time periods defined (0-63 days, 0-42 days, 0-21 days). Numbers

with an asterisk indicate that that group was significantly different at the 0.05

significance level than the AVA SQ group, based on the Wilcoxon Rank Sum test.

10

Table III. Median (Mean) Area Under the Curve (AUC), Time to Maximum Concentration (Tmax), and Maximum Concentration (Cmax) by Treatment Group						
	AVA SQ	AVA + K SQ	AVA + 10103 SQ	AVA+7909 SQ	AVA+7909 IM	p-value**
Through Day 63						
AUC	27,247,740 (72,440,976)	30,215,702 (34,771,333)	122,771,755 (213,490,038)	43,564,150 (49,416,690)	25,522,306 (35,012,286)	0.32
Tmax	49 (49)	49 (51.8)	49 (53.2)	*56 (53.2)	*56 (53.2)	0.35
Cmax	2,350,000 (8,491,400)	2,080,000 (2,164,000)	10,867,300 (25,783,660)	2,205,000 (4,013,800)	1,600,000 (2,929,600)	0.25
Through Day 42						
AUC	2,163,950 (2,761,226)	4,419,240 (7,507,173)	*11,657,355 (10,965,198)	*5,479,006 (6,094,460)	5,969,975 (4,922,086)	0.036
Tmax	35 (27.4)	35 (27.4)	16 (18.4)	16 (23.6)	16 (17)	0.28
Cmax	125,000 (155,932)	246,000 (356,222)	*548,000 (605,512)	*284,500 (310,522)	384,250 (285,132)	0.048
Through Day 21						
AUC	492,292 (620,416)	1,108,240 (2,402,633)	*4,283,805 (4,289,102)	*2,052,506 (2,216,740)	2,985,975 (2,196,426)	0.035
Tmax	16 (16)	16 (15)	16 (17)	16 (17)	16 (17)	0.42
Cmax	67,600 (86,322)	164,300 (319,814)	*539,300 (600,312)	284,500 (258,672)	384,250 (285,132)	0.034

* p < 0.05 in comparison to AVA SQ, using the Wilcoxon Rank Sum test
** p-value based on Kruskal-Wallis test comparing all 5 treatment groups

Statistical comparisons were made using nonparametric tests. For each

15   outcome, the 5 treatment groups were compared overall, using the Kruskal-Wallis

test. In addition, for each outcome, the Wilcoxon Rank Sum test was performed for

the AVA Alone group versus each of the 4 other treatment groups separately.

48

Outcomes that were significantly different from AVA Alone group by the Wilcoxon Rank Sum test at p<0.05 are indicated by an asterisk in the tables.

All analyses included all 25 NHPs in the experiment. No adjustments for the multiple significance tests were made. The significance tests are provided to guide
5   interpretation of the data only. The fact that there are only 5 animals in each group means that differences that may be clinically important will not necessarily be statistically significant. On the other hand, because of the multiple significance tests performed, some of the differences noted may be due to chance alone.

The geometric means of the anti-PA IgG titers on each day are shown in
10   Table IV, along with the p-values comparing all 5 treatment groups. Numbers with an asterisk indicate that that group was significantly different at the 0.05 significance level from the AVA Alone group on that day. Some significant increases in geometric mean titers were noted when comparing groups receiving AVA in combination with a CpG ODN on Days 11, 16, 21, 28, 35, 42, and 49 compared to
15   AVA Alone. The geometric means of the anti-PA IgG for all groups and all time points are plotted in Fig. 6.

Table IV. Anti-PA IgG Geometric Means Titer						
Study Day	AVA SQ	AVA + K SQ	AVA + 10103 SQ	AVA+7909 SQ	AVA+7909 IM	p-value**
10 days pre	224	1,935	282	538	75	0.47
1	136	72	1,420	247	55	0.77
4	381	633	318	243	18	0.84
11	10,850	35,558	*69,896	*70,334	28,685	0.059
16	72,922	119,545	*538,025	183,630	212,095	0.059
21	35,370	61,983	*310,753	*127,623	*165,425	0.029
28	94,204	114,936	*325,414	119,436	93,301	0.101
35	119,719	182,093	*319,666	227,795	59,609	0.018
42	45,397	63,868	97,958	*184,346	61,636	0.24
49	4,323,503	1,541,858	8,143,388	1,563,387	*926,026	0.058
56	808,048	1,324,476	1,340,915	2,698,954	2,014,763	0.26
63	859,924	508,446	1,867,685	653,155	670,124	0.21

* p < 0.05 in comparison to AVA sc, using the Wilcoxon Rank Sum test
** p-value based on Kruskal-Wallis test comparing all 5 treatment groups

20

The earliest time a meaningful antibody titer was detected in animals was 11 days after the initial injection. Four of 5 and 5 of 5 animals receiving AVA + CpG 10103 SQ and AVA + CpG 7909 IM, respectively, had peak IgG concentrations at

49

day 16. Whereas, 3 of 5, in the group receiving AVA + CpG 7909 SQ, and 2 of 5 in

the groups receiving AVA alone or AVA + K type ODN had peak IgG

concentrations at day 16. The remaining animals in these groups had peak

concentrations at week 5. There was variability in responses between animals

5   consistent with other vaccine preparations. As there were significant differences at

some time points in each group receiving AVA with a CpG ODN, it appears that

CpG ODN are increasing anti-PA antibody titers earlier during the immunization

process.

       Anti-PA IgM titers were determined by ELISA at baseline and up to 16 days

10   after the first injection. Fig. 7 shows the geometric mean anti-PA IgM titers in all 5

study groups. The geometric mean TNA titer on each day is shown in Table V,

along with the p-values comparing all 5 treatment groups. Numbers with an asterisk

indicate that that group was significantly different at the 0.05 significance level from

the AVA Alone group on that day. Significant differences were noted on days 4, 11,

15   16, 35, 42, and 56 (see also Fig. 8).

Table V. Geometric Mean TNA Titer

Day	AVA SQ	AVA + K SQ	AVA+ 10103 SQ	AVA+ 7909 SQ	AVA+ 7909 IM	p-value**
4	750	564	818	*278	674	0.10
11	709	3,990	· *5,880	*6,659	2,295	0.04
16	9,923	*40,130	*36,453	*84,737	13,095	0.003
21	30,566	49,148	38,805	67,262	24,579	0.13
28	58,216	46,442	102,761	137,442	31,483	0.07
35	32,348	39,984	59,652	*168,815	24,991	0.04
42	20,409	29,759	*68,738	*80,926	17,593	0.02
49	1,170,338	403,990	1,492,207	885,196	1,135,368	0.12
56	227,357	195,412	*914,143	262,595	*472,711	0.01
63	464,681	246,756	598,617	313,282	414,113	0.20

       * $p < 0.05$ in comparison to AVA sc, using the Wilcoxon Rank Sum test

20   ** p-value based on Kruskal-Wallis test comparing all 5 treatment groups

       The correlation of TNA titers with anti-PA IgG titers was examined.

Specifically, using linear regression models, TNA titer was plotted versus anti-PA

IgG titer and correlation coefficients and probabilities were calculated. Correlations

50

were statistically significant (P<0.05) between the titers of the two analytes on days

11, 21, 28, 35, 42, and 63.

Example 4

Mouse Seroprotection Assay

Mice were passively immunized with pooled serum collected from NHPs on

days 11 and 16 post their first immunization. The four vaccine groups for which

serum was pooled included AVA alone, AVA+CpG10103 SQ, AVA+CpG7909 SQ,

and AVA+CpG7909 IM. Serum from a control group of untreated NHPs and from a

pool of pre-treatment serum was also tested. Two experiments were performed (10

mice/group). Twenty-four hours after injecting mice IV with 0.1 mL of a pooled

antiserum, serum was collected from 4 mice in each group and anti-PA IgG titers

determined.

Mice were followed for survival after an i.p. challenge with 30-60 LD_{50} of

Sterne strain anthrax spores. Statistical analysis on survival data was performed

using the log-rank test within the PROC LIFETEST of SAS software for Windows,

Version 8.2. Table VI summarizes the percentage survival of treatment and control

groups of mice in both experiments.

Table VI. Percentage Survival of Mice Post Injection with Pooled NHP Serum and Challenge with Anthrax Spores (N = 10 mice per group)

Vaccination Group	Experiment 1		Experiment 2	
	Percentage Survival			
	Day 11 serum	Day 16 serum	Day 11 serum	Day 16 serum
AVA	10	50	10	20
AVA+10103 SQ	40	40	0	60
AVA+7909 SQ	60	70	40	40
AVA+7909 IM	50	30	10	20
Control	0		0	
Pre-Treatment Bleed	10		10	

For NHP Serum Collected on Day 11 (two experiments combined), the

survival curves were significantly different by the log-rank test when all 6 groups

were included (p = 0.0002), but were not significantly different when the 2 control

groups were excluded (p = 0.12). The pairwise analyses comparing the AVA-CpG

51

combinations to AVA alone gave one significant result, for AVA+CpG7909 SQ (p = 0.02). For NHP Serum Collected on Day 16 (two experiments combined), the survival curves were significantly different by the log-rank test when all 6 groups were included (p < 0.0001), but were not significantly different when the 2 control

5   groups were excluded (p = 0.12). The pairwise analyses comparing the AVA-CpG combinations to AVA alone did not give any significant results.

Overall survival percentages for each treatment group were plotted versus the arithmetic mean anti-PA IgG titer of mouse sera collected for each treatment group 24 hours after injection of NHP serum just before anthrax spore challenge

10   (Fig. 9). Linear regression was used to fit a line to the data points to be used as a predictor of the serum titer needed to be circulating in mice at the time of challenge to achieve protection against an injection of 30 to 60 LD_{50} of anthrax spores. The two data points with titers above 6,000 were excluded from the calculation of the regression line. Interpolating from the regression line, this data suggest that it takes

15   a circulating anti-PA IgG titer of 2,500 to protect 50% of mice from a lethal challenge of 30 to 60 LD_{50} of anthrax spores.

Thus, CpG ODN can be safely administered in amounts of 250 μg in combination with the approved human dose of AVA to rhesus macaques. The combination of CpG ODN with AVA increased the total anti-PA IgG concentration

20   after a single priming immunization compared to the group receiving AVA alone. The peak response was also accelerated in time for more of the animals receiving AVA + CpG 10103 and CpG 7909 compared to AVA alone. Although antibody titers were statistically significantly increased at some time points in some of the groups immunized with AVA in combination with CpG ODN compared to AVA

25   alone, the numbers of animals per group were relatively small, and therefore, the statistical significance of these results should be viewed with caution. However, the results overall are highly encouraging that this combination may potentiate the development of protective antibodies when B type CpG are combined with the licensed anthrax vaccine.

52

Example 5

Effect of CpG ODN on the protective efficacy of AVA

The critical measure of an antigen-adjuvant combination is its ability to

5   induce protective immunity. Based on results indicating that the immune response

of macaques to AVA was improved by the co-administration of CpG ODN, studies

to demonstrate the protective efficacy of CpG ODN with AVA were undertaken.

Due to restrictions associated with the use of macaques in trials involving lethal

anthrax challenge, the widely accepted guinea pig model was employed. Normal

10   guinea pigs succumb rapidly to challenge by 50 LD50 Ames strain anthrax spores

(Table VII). Immunization and boosting with AVA alone improved survival,

although most animals still died from infection (Table III). By comparison, nearly

75% of the animals immunized and boosted with CpG-adjuvanted vaccine survived

(p = .05). Co-administering CpG ODN with AVA also resulted in a modest increase

15   in the MTD of the challenged animals, although this effect did not reach statistical

significance.

Table VII.   Effect of CpG ODN plus AVA on the survival of guinea pigs challenged with anthrax

20

	# Surviving/total	% Surviving	MTD (days)
Untreated	1/28	3.6	2.1
AVA	15/32	46.9	6.1
AVA + CpG ODN	23/31*	74.2	6.9

25

Guinea pigs were immunized on day 0 and boosted on week 4 with AVA
plus 100 - 300 μg of an equimolar mixture of CpG D ODNs 1555, 1466 and K3 (all
known to be active in this species). Six weeks later they were challenged IM with
30   50 LD50 Ames spores. Survival and mean time to death (MTD in days) is shown.
*   Significantly improved survival compared to animals immunized with AVA
alone, p = 0.05.

53

The fraction of guinea pigs surviving otherwise lethal anthrax challenge was
significantly improved by co-administration of CpG ODN with AVA. Without
being bound by theory, several characteristics of CpG ODN contribute to their utility
as immunotherapeutic agents. First, a single dose can provide protection for several

5   weeks, allowing ODN to be administered to "at risk" populations (e.g., medical
and/or military personnel) in advance of potential pathogen exposure (Elkins et al.,
J. Immunol. 162:2291, 1999). Repeated doses can extend the duration of protection
for many months (Klinman et al., *Infect. Immun.* 67:5658, 1999). Second, CpG
ODN are effective against a wide range of pathogens, and thus may be of use before

10   the causative agent has been identified. Third, CpG ODN improve the innate
immune response of individuals whose adaptive immune response is impaired (such
as newborns and the elderly), and thus can provide broad population-based
protection against infection (Klinman et al., *Immunity* 11:123, 1999).

        Furthermore, repeated doses of CpG ODN can be safely administered to

15   rodents and primates without adverse consequences (Verthelyi et al., *J. Immunol.*
168:1659, 2002; Klinman et al., *Infect. Immun.* 67:565, 1999). In the present
example, animals treated with CpG ODN (alone or in combination with anthrax
vaccine) remained healthy and active prior to pathogen challenge.

20   **Example 6**

Dose and timing of CpG administration influences CpG-mediated protection in
mice exposed to Ebola virus

        In order to demonstrate the effect of CpG dosage on protection from Ebola
virus, mice were treated with 25 - 150 μg of CpG ODN on day 0, and then

25   challenged with 300 LD50 of mouse-adapted Ebola Zaire. As shown in Fig 3a, mice
treated with 100-150 μg of CpG ODN attained maximal protection from the virus.

        In order to determine the effect of timing of CpG administration on
protection from Ebola, mice were treated with 100 μg of CpG ODN on the day
shown, and then challenged with 300 LD50 of mouse-adapted Ebola Zaire. As

30   shown in Fig 3b, mice showed maximal protection from Ebola infection when CpG
ODN were administered concurrently with Ebola exposure. However, partial

54

protection was attained when CpG ODN were administered up to three days prior to exposure or up to three days after exposure.

Example 7

5   **CpG ODNs increase survival times in mice exposed to anthrax spores**

In order to demonstrate that CpG ODNs increase survival times in mice exposed to anthrax spores, mice were treated at the times shown with 100 μg of CpG ODN, and then challenged with 11 LD 50 anthrax spores. As shown in Fig 4, CpG administration increased survival times in mice exposed to anthrax spores.

10

Example 8

Adjuvant effect of CpG ODN with AVA/rPA in mice

This example demonstrates the adjuvant effect of CpG ODN with AVA/rPA in mice. Mice were immunized with 2.5 μg of rPA or 5 μg of AVA plus 50 μg of

15   CpG ODN. The magnitude of the IgG anti-PA response and IFNγ response 10 days after the second immunization is shown below (N = 4 mice/group).

Table VIII. Effect of CpG ODN on the immune response of mice to AVA and
rPA

Group	IgG anti-PA titer (x 1000)	IFNγ production
Naive	0	0
AVA	13+8	250+125
AVA + CpG	15 + 12	757 ~ 87
rPA	45 + 3	254 + 163
rPA+ CpG	182 + 61	343 + 148
CpG	0	0

Example 9

Effect of CpG ODN alone (no antigen) to prevent infection by TBEV

30   This example demonstrates the efficacy of CpG ODN alone in preventing infection by tick-borne encephalitis virus. Mice were injection on the day shown

55

with 100 µg of CpG ODN. They were challenged with TBEC, and survival monitored. N = 10/group.

Table IX. Effect of CpG ODN on the immune response of mice to tick borne encephalitis virus

Group	Percent surviving (day 12)
Control ODN	0
CpG ODN day 0	80
CpG ODN day 2	30
CpG ODN day 4	20

Example 10

Effect of K ODN on the avidity of the anti-PA response

This example demonstrates the effect of K ODN on the avidity of the anti-PA response. Animals were treated with ODN as described in Elkins et al., *J. Immunol.* 162:2291, 1999. Fig 5 shows that K ODN increase the avidity of the anti-PA response.

Example 11

Effect of Poly (Lactide-Co-gGycolide) (PLG) Microparticle

Formulation of DNA onto cationic poly(lactide-coglycolide) (PLG) microparticles, has been developed as a means to better target DNA to antigen-presenting cells (APCs). PLG microparticles are an attractive approach for vaccine delivery, since the polymer is biodegradable and biocompatible and has been used to develop several drug delivery systems (Okada et al, *Adv. Drug Deliv. Rev.* 28:43-70, 1997). In addition, PLG microparticles have also been used for a number of years as delivery systems for entrapped vaccine antigens (Singh and O'Hanagan, *Nat. Biotechnol.* 17:1075-1081, 1999). More recently, PLG microparticles have been described as a delivery system for vaccines, such as entrapped DNA vaccines (Hedley et al., *Nat. Med.* 4:365-368, 1998; Jones et al., *Vaccine* 15:814-817, 1997;

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U.S. Patent No. 6,309,569; U.S. Patent   6,565,777; U.S. Patent No.
6,548,302).

       Encapsulating a bioactive agent in a polymer microparticle, such as a PLG
microparticle generally includes (1) dissolving polymer in a solvent to form a
5   polymer solution; (2) preparing an aqueous solution of the bioactive agent, such as
the CpG ODN; (3) combining the polymer and bioactive agent solutions with
agitation to form a water-in-oil emulsion; (4) adding the water-in-oil emulsion to a
further aqueous phase containing a stabilizer or surfactant with agitation to form a
(water-in-oil)-in-water emulsion; (5) adding the (water-in-oil)-in-water emulsion to
10   excess of an aqueous phase to extract the solvent, thereby forming polymer
microparticles of a size up to 10 microns in diameter. The microparticles contain the
bioactive agent. Generally, the polymer includes or consists of PLG of molecular
weight of 40kD or lower (see U.S. Patent No. 6,309,569). In one example, the
molecular weight of the PLG is 30kD or lower. In other examples, the
15   microparticles include PLG of 3kD, 6kD, 9kD, 22kD and mixtures thereof. It has
been proposed that the molecular weight range of suitable polymer is 1.5kD -250kD,
and commercial preparations of 3, 6, 9, 12, 18, 22, 60, 65 & 90kD PLG have been
utilized (see U.S. Patent No. 5,309,569). It is believed that the hydrolysis rate of the
polymer is related to the molecular weight. Thus, lower molecular weight polymers
20   degrade more rapidly.

       The effectiveness of cationic microparticles with adsorbed DNA at inducing
immune responses was investigated in mice. The PLG polymer (RG505) can be
obtained from Boehringer Ingelheim.

25   Several exemplary protocol for the preparation of cationic microparticles
using a modified solvent evaporation process follows.

       1. Briefly, the microparticles were prepared by emulsifying 10 ml of a 5%
(wt/vol) polymer solution in methylene chloride with 1 ml of phosphate-buffered
30   saline (PBS) at high speed using an IKA homogenizer. The primary emulsion was
then added to 50 ml of distilled water containing cetyltrimethylammonium bromide
(CTAB) (0.5% wt/vol), resulting in the formation of a water-in-oil-in-water

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emulsion, which was stirred at 6,000 rpm for 12 hours at room temperature, allowing
the methylene chloride to evaporate. The resulting microparticles were washed twice
in distilled water by centrifugation at 10,000 × g and freeze-dried. DNA was
adsorbed onto the microparticles by incubating 100 mg of cationic microparticles in

5   a 1-mg/ml solution of DNA at 4°C for 6 hours. The microparticles were then
separated by centrifugation, the pellet was washed with TE (Tris-EDTA) buffer, and
the microparticles were freeze-dried. Physical characteristics were monitored as
previously described (see Singh et al., *Proc. Natl. Acad. Sci. USA* 97:811-816;
O'Hagan et al., *J. Virol.* 75 (19):9037–9043, 2001).

10   2. Cationic microparticles were prepared by using a modified solvent
evaporation process. Briefly, the microparticles were prepared by emulsifying 10 ml
of a 5% (wt/vol) polymer solution in methylene chloride with 1 ml of PBS at high
speed using an Ika homogenizer (Ika-Werk Instruments, Cincinnati, OH). The
primary emulsion then was added to 50 ml of distilled water containing

15   cetyltrimethylammonium bromide (CTAB) (0.5% wt/vol). This resulted in the
formation of a water/oil/water emulsion that was stirred at 6,000 rpm for 12 hours at
room temperature, allowing the methylene chloride to evaporate. The resulting
microparticles were washed twice in distilled water by centrifugation at 10,000 g and
freeze-dried. For preparing PLG-dimethyl dioctadecyl ammonium bromide (DDA)

20   and PLG-1,2-dioleoyl-1,3-trimethylammoniopropane (DOTAP) microparticles,
DDA or DOTAP was dissolved in the polymer solution along with PLG polymer,
and the primary emulsion then was added to 0.5% polyvinyl alcohol solution to form
the water/oil/water emulsion (see Singh et al., *Proc. Natl. Acad. Sci.* 97:811-816,
2000).

25   After preparation, washing, and collection, DNA was adsorbed onto the
microparticles by incubating 100 mg of cationic microparticles in a 1 mg/ml solution
of DNA at 4°C for 6 hours. The microparticles then were separated by
centrifugation, the pellet was washed with Tris-EDTA buffer, and the microparticles
were freeze-dried (see Singh et al., *Proc. Natl. Acad. Sci.* 97:811-816, 2000).

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For the studies described below, the CpG ODN was conjugated to the PLG, whereas the rPA was free (but was co-administered after mixing with the PLG-ODN).

Mice were immunized with either 2.5, 8 or 25 μl of AVA, AVA plus CpG
5   ODN, AVA plus PLG-CpG, AVA plus GpC ODN (a control), AVA plus PLG-GpG ODN (and additional control), or AVA plus PLG (a further control). The IgM anti-PA titer, IgG anti-PA titer, IgG1 anti-PA titer, IgG2a anti-PA titer, and survival of the animals were monitored.

The results indicated that mice immunized with a single dose of AVA plus
10   CpG or poly (lactide-co-glycolide) microparticle (PLG)-encapsulated CpG through cross-linking developed specific antibody responses as early as day 11 post-immunization. The antibody response elicited by the AVA-CpG-ODN immunogen was five to one hundred times greater than that of mice immunized with AVA alone or AVA plus control ODN or PLG-control ODN. Immunization of AVA plus CpG
15   or PLG-CpG also elicited a stronger TH1 response with higher ratios of IgG2a /IgG1 than control groups. Whereas most of control mice died after a challenge with 300-9000 LD50 of Sterne strain spores (STI) of *Bacillus anthracis* at week 1 and 2 post-immunization, a 70 - 100% survival rate was observed in mice immunized with AVA plus CpG or PLG-CpG. These results suggested that using CpG or PLG-CpG
20   as adjuvants not only improved the immunogenicity and protection of AVA against STI spore challenge, but also accelerated specific immune responses with great potential for counter-bioterrorism usage.

25   It will be apparent that the precise details of the methods or compositions described may be varied or modified without departing from the spirit of the described disclosure. We claim all such modifications and variations that fall within the scope and spirit of the claims below.